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FABRICATION OF A 1/10 DYNAMICAILY SCALED GEOMETRICALLY SIMILAR, STRUCTURAL REPLICA OF THE APOLLO SERVICE MODULE SHELL & STRUCTURE

NASA CONTRACT NAS9-4567

PHASE II
FINAL REPORT

Submitted to:

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
Manned Spacecraft Center
Houston, Texas

Submitted by:

ATKINS & MERRILL, INC.
Sudbury, Massachusetts

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Project Engineer

Approved by: Robert H. Girvin
Robert H. Girvin
Engineering Manager

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I. INTRODUCTION

Under Phase II of the NASA contract, NAS9-4567, Atkins & Merrill, Inc . fabricated a 1/10 scale, geometrically similar, structural replica of the Apollo Service Module shell. Also supplied was an abbreviated Lunar Module Cone extension aft of the Service Module, a fairing between the Command Module and Service Module, a modified Command Module base plate and a model sting. This model was instrumented using strain gages, accelerometers and a thermocouple to record model response and temperature. Prior to delivery of the final assembly, a vibration test was performed to determine the integrity of the fasteners & structural components.

During the Phase I feasibility study, model techniques were developed for fabrication of a true replica model of the outer honeycomb curved panel shell structure and the radial beams. Other internal support members were simulated for mass or stiffness and location of the C.G. Whenever possible the actual methods and processes used in the full scale design were adhered to in construction of the true replica 1/10 scale model components. In the following detail component descriptions, reference will be made to the Phase I report which details the component fabrication processes developed during that period of the contract. Photographs of the model components and assemblies are located and listed at the end of the report. A final model assembly drawing, A & M No. J66855, has been included at the end of this report.

II. MODEL DESCRIPTION

A. Outer Curved Panel Shells

The eight individual honeycomb curved shell segments were reproduced in detail by a 1/10 scale linear reduction of all dimensions for the honeycomb core, face sheets, edging, and fasteners. The densified core material required at the outer edges of the panels was simulated by compressing a predetermined extended edge of the 2.3 lb/ft^3 core material to provide a final outer edge density equivalent to the 8.1 lb/ft^3 core material used on the full scale panels. This was necessary because the fabrication of the 8.1 lb/ft^3 honeycomb core material was beyond the capabilities of miniature honeycomb core material manufacture.

Fixtures were designed and manufactured to obtain the radius curvature of the outer panels. Each frame was prefabricated to the required segment size and tolerance. Then the frames, preformed core and face sheet were vacuum bagged in the radius curvature fixture and bonded into one integral unit.

The fabrication methods and processes used in the honeycomb panel manufacture were determined during the Phase I study and are documented in Sections III A, B, C and D of that final report. Photographs 1, 2, 6 and 8 illustrate components of the panels and photographs B and D show a completed panel segment.

B. Radial Beams

The basic design was a 1/10 linear reduction of the detail dimensions for beam No. 2 with the following exceptions:

a. The width and taper of the inner flanges of the beam caps in the spacecraft axial direction were simulated as per each individual beam configuration.

b. The compression and shear - tension truss structure at the top of the beams was simulated with the 1, 3, and 5 compression truss structure configuration machined per NAA drawing beam No.5 and the 2, 4, and 6 shear - tension truss structure configuration machined per NAA drawing beam No. 2.

The manufacturing process used to fabricate the radial beams was; to machine mill from solid aluminum plate then chemical mill in a heated alkaline etching solution to the final 1/10 scale dimensions. A detailed description of this method is found in Section III F of the Phase I final report. Techniques were refined in the control of the chemical milling process during Phase II which resulted in more accurate dimensional stability during the etching procedure and less hand finishing. Photograph No. 11 depicts a machined radial beam and No. 12 a finished chemically milled beam.

C. R.C.S. Panel Shells

These four panels were reproduced in detail by a 1/10 scale linear reduction of all dimensions for the honeycomb core, edging and face sheets. The core required for the R.C.S. Panels was of the .025 inch hexagonal cell configuration; .100 inch thickness and .00015 inch thick 5052-H39 aluminum alloy foil with a 3.4 lbs per cubic ft. density. A face sheet material of 2024-T81 aluminum, .0025 thick was used for the sandwich panel fabrication. Neither the side hinges nor the fuel fill ports were reproduced in the model. The process and fabrication methods are identical to those followed in Section II A of this report. Photographs B, D and E show the completed R.C.S. panel assembly.

D. Forward Bulkhead Panels

The six pie-shaped bulkhead panels were reproduced by a 1/10 scale linear reduction of the outer edging, internal rings, face sheet thickness and configuration, and overall panel thickness. Since these panels were not to be replica model component, it was agreed with NASA Engineering that a larger than scale cell size honeycomb core material of proper density could be satisfactorily substituted in the forward and aft bulkheads. The size selected was .125 hexagonal cell X .0007 inch 5052-H39 aluminum alloy foil having a density of 3.1 lbs. per cubic foot. Additional adhesive is used at the edge joints to improve the joint strength at the larger core interface.

The process and fabrication methods used in manufacturing these segmented panels are identical to those followed in Section II A of this report except a flat holding fixture was used to lineup and hold the components during the bonding operations. Photographs F and G show the forward bulkhead components in the completed assembly.

E. Aft Bulkhead Panel Assembly

The six individual honeycomb sandwich panels were fabricated as separate pie segments then bonded together along common edges as one full cylindrical bulkhead unit. The outer face skins, inner panel cylindrical rings, and panel interface components were a 1/10 scale linear reduction of the full scale parts. Again, as with the forward bulkhead panels, the .125 cell X .0007 foil honeycomb core material was substituted in place of an actual 1/10 scale reduced core configuration.

The process and fabrication methods are identical to those followed in Section II A and II D of this report. Photographs C, H and N illustrate the aft bulkhead components in the completed assembly.

F. Interior Shelf, Stiffness and Braces

These internal parts are used, along with the forward and aft bulkheads, to support and lineup the radial beams prior to the assembly of the outer curved panel shell segments. They consist of a shelf at Sector I, various struts and curved braces between the other sectors. These components simulate, at an approximate 1/10 scale, the stiffness of the full scale parts. The mass of the 1/10 scale parts has been kept to a minimum and the mounting methods and locations simulate the full scale interior bracing. Miniature rivets and screws are used to fasten these components to the radial beams.

The Aluminum Alloy materials which are specified on the full scale part drawings, have been used to fabricate the 1/10 scale components. Photographs C, F, H, and M illustrate the interior parts in the assembly.

G. Command Module to Service Module Fairing

This cylindrical fairing, illustrated in Photograph J, is split into two half sections. It is fabricated of aluminum sheet stock to simulate the stiffness of the full scale honeycomb segmented fairings. The aft end is fastened with miniature screws to the forward ring of the 1/10 scale service module. A rubber sealing gasket is provided between the upper fairing edge and the command module adapter base plate. Photographs H, M, F, Q and others show this fairing fastened to the S/M and mating up with the C/M base plate.

H. Command Module Adapter Base Plate

This base plate was machined to mate with and mount to the six radial beam truss shaped extensions (see Photograph M). Adjustable fittings are provided to tie the model to the base plate at three tension points and six compression points. The model is supported in the wind tunnel by this base plate which in turn is fastened and keyed solidly to the sting shaft at the center bore of the base plate. Photograph Q shows the completed model mounted to the C/M base plate and the sting.

J. Sting

A model sting was machined from a one-piece, high strength alloy steel hollow bar, approximately 6 1/2 ft. long X 5 inch O.D. The forward end of the sting adapts to the command module base plate. The aft end adapts to the movable knuckle of the wind tunnel model support system. Provisions are made in the sting to allow for instrumentation leads to be routed through the hollow center of the sting shaft.

K. Abbreviated L.E.M. Cone

This conical adapter section was fabricated of aluminum alloy sheet material (see Photograph I) and is the same stiffness as the full scale honeycomb structure. This part is fastened to the aft bulkhead of the 1/10 scale service module using approximately 200 miniature self tapping screws and extends 10 inches beyond the aft bulkhead. The aft end of this cone is then attached to the sting by means of an adjustable split ring. The ring can be adjusted to lineup the model on the sting and eliminate any build-up of stress in the model during assembly to the sting and command module base plate (see Photographs N and Q).

L. Simulated R.C.S. Engines

The external engine housings and nozzles were simulated by a direct 1/10 scale linear reduction of the exterior size dimensions (see photograph D). These components were attached to the R.C.S. panels with eight miniature threaded fasteners through inserts which were bonded into the honeycomb sandwich panels (See photograph E).

M. Simulated R.C.S. and Service Module Engine Fuel Tanks

The internal R.C.S. engine tanks (see photograph E), fuel, oxidizer, and helium, were fabricated of steel bar stock per NASA supplied drawings. The mass and size of these tanks is simulated at the four R.C.S. engine locations. Brackets of similar design to the full scale were fabricated in 1/10 scale to mount the simulated tanks to the interior R.C.S. honeycomb panels.

The service module main engine fuel tanks were machined from brass bar stock and simulate 1/1000 the mass of the full scale tanks. Adaptor plates are provided on the aft bulkhead at sectors 2, 3 ,5 and 6 for mounting these brass weights. These weights, which are not attached to the model except during tunnel testing, are stored in the model instrument case on a mounting plate which has been provided. Each weight is numbered as to its sector location in the model.

N. Final Model Assembly

Each component of the model was completed in its entirety prior to the final assembly operation. A fixture was designed for the internal radial beam - forward and aft bulkhead sub-assembly. This fixture was used to line up, locate and hold the components in position to the prescribed 1/10 scale tolerances of .001 inch. While held in position and confined as a total sub-assembly, a match drilling operation was performed to join the forward and aft bulkhead components to the radial beams and outer cylindrical ring. Then, using an epoxy adhesive and a reduced quantity of equally spaced 1/10 scale aluminum alloy rivets, the bulkhead panel edging was attached to the radial beams. The internal shelf, stiffeners and braces were then positioned between the radial beams, match drilled, and fastened in place using miniature screws and rivets. This completed sub-assembly is illustrated in photographs C, F, and A. A torsional brace was fastened between the sector six radial beam truss and the sector six forward bulkhead panel. (See Photograph G)

This internal structure sub-assembly was then repositioned on the alignment fixture and mounted onto a rotary dividing head table. All eight outer curved panels along with the four R.C.S. panels and two small hatches were positioned on this structure. This complete assembly was then match drilled on a Bridgeport Milling Machine using a special hand operated drilling tool. A clearance hole for a .60 mm X 169 TPI stainless steel threaded fastener was drilled through the flanged edge of all outer panels, the edges of radial beam, the lower and upper bulkhead cylindrical rings, and through the command module to service module fairing ring. Previously manufactured special miniature nut plate strips were then bonded to the rear surface of the radial beams and rings at each hole location. All panel shell components were then fastened to the inner structure using the same quantity and scaled spacing of the .60 mm X 169 TPI screws as are used on the full scale service module assembly. Each screw was then torqued at this assembly to equal the same stress level produced in the full scale fasteners.

Next the 10" long L.E.M. Cone extension was positioned on the aft bulkhead and match drilled and fastened into position.

The complete model assembly is illustrated in Photographs L, M, N, P, Q and on A & M Drawing No. J 66855-B.

III. INSTRUMENTATION

A. A set of four Dentronics, Inc. three-axis stacked rosette type strain gages, No. 232C13 R3-45E STK, were bonded to the aft outside surface of radial beam No. 5. (See Photograph H.) The leads to these strain gages are carried through the aft bulkhead and terminate at the sting in the L.E.M. Cone area. The connector or terminal for these gages will be supplied by NASA Langley.

B. Eight Columbia Model 606-2 miniature accelerometers, supplied by NASA, Langley Field, were bonded with an epoxy adhesive to the inner surface of four curved panel shells sections. (See Photograph A) The NASA serial number and accelerometer locations are called out on A & M Drawing No. J66855-B which is included at the end of this report. The three foot long accelerometer leads extend through the service module aft bulkhead into the L.E.M. Cone area.

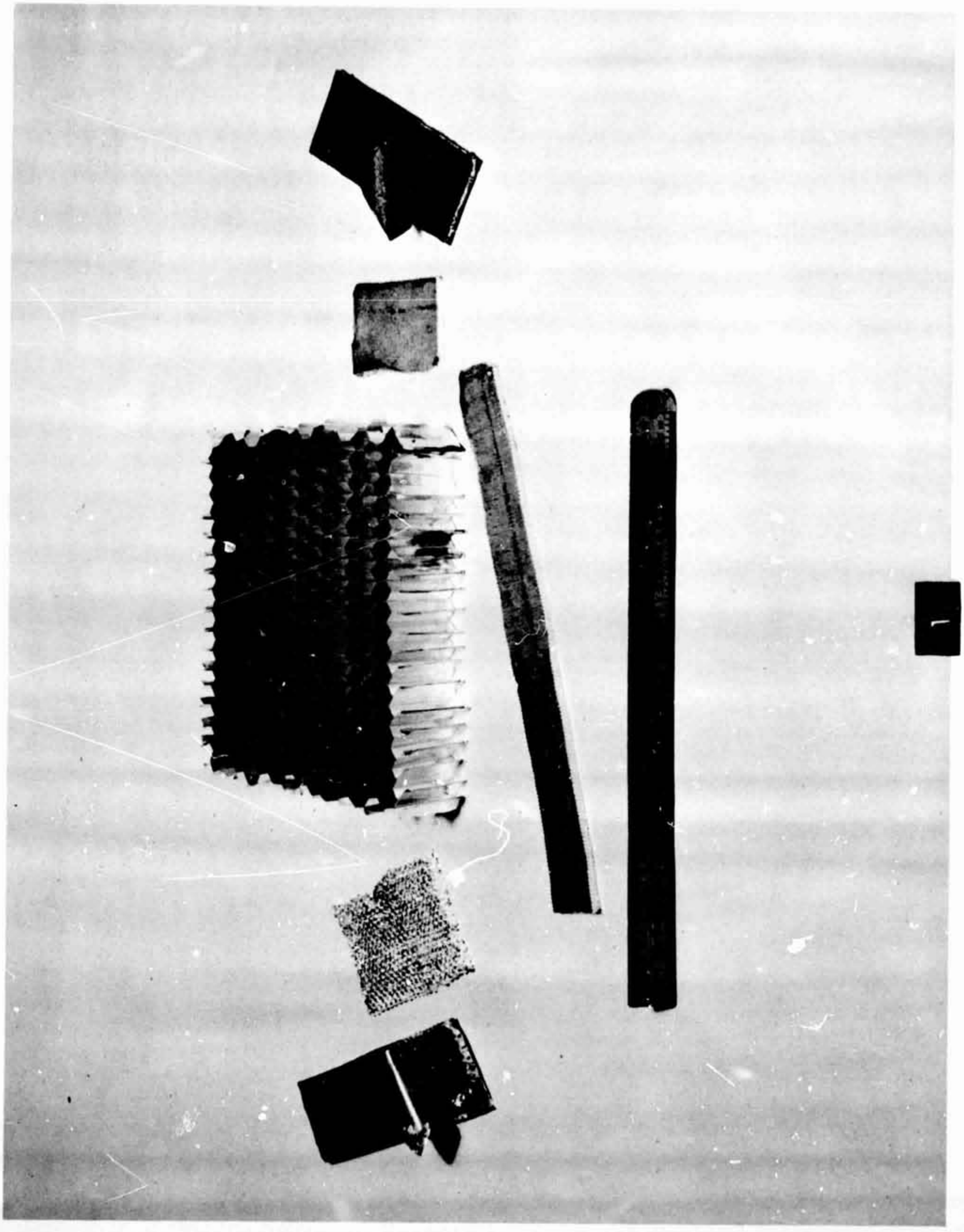
C. An iron-constantan thermocouple wire of 100 ft. length has been bonded at a point on the inside skin of Panel No. 3. This thermocouple was included at the request of NASA. It became apparent that there was a possibility of distortion in this panel of elevated temperatures during a secondary bonding operation of the fabrication process. While the exact temperature at which this panel will distort or even if it will distort is unknown, it was agreed by Atkins & Merrill and NASA that the temperature of this panel should be monitored and the testing discontinued if its temperature reached 140°F.

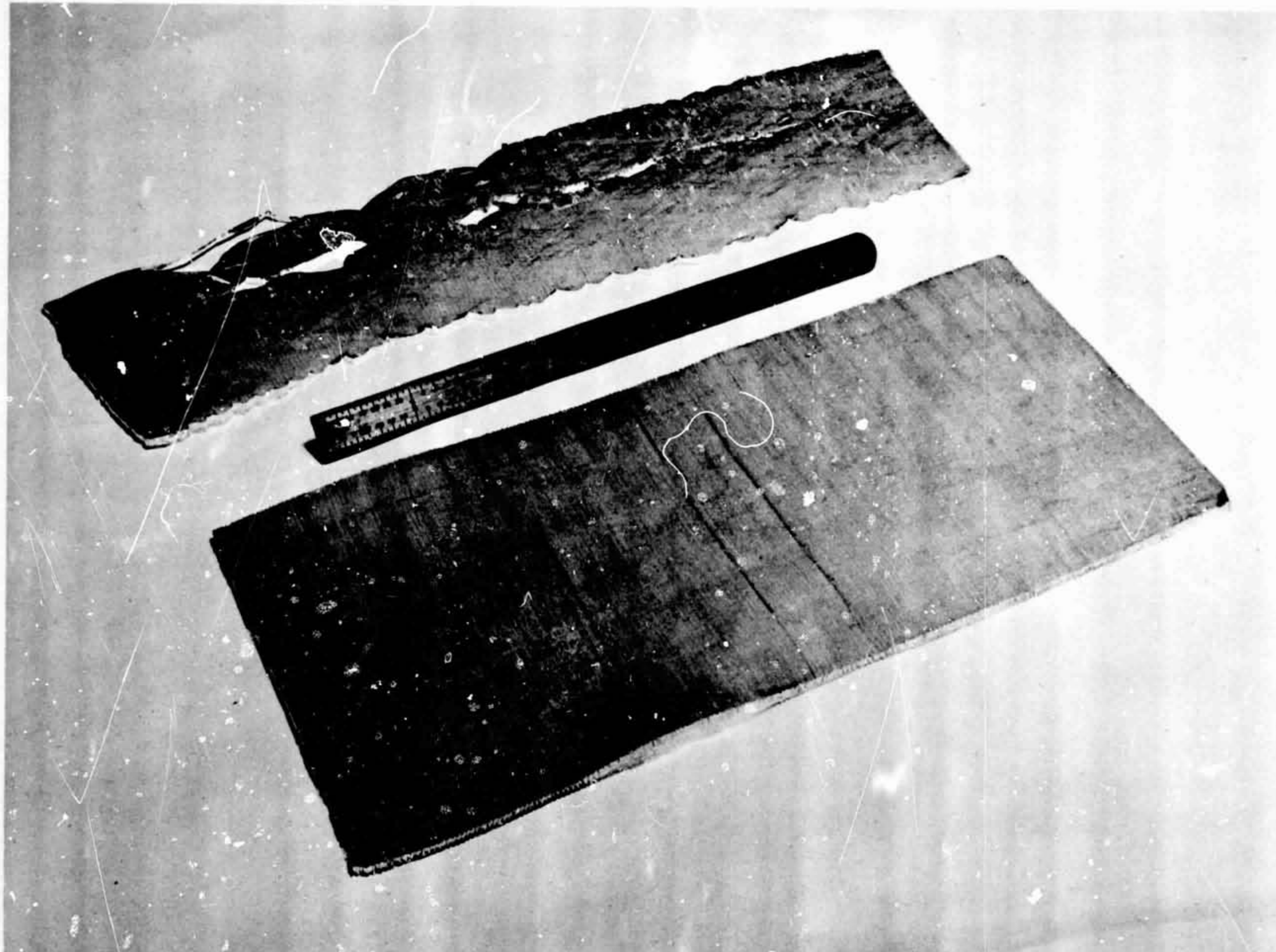
IV. VIBRATION TEST

An acoustic test of the 1/10 scale Apollo Service Module Model Assembly was conducted on 16 April 1968. A NASA representative was present to conduct and witness this test. A test report concerning the procedures and results of this test is on file at NASA, MSC. This report confirms that the model passed all the requirements of the acoustic vibration tests and was accepted by the NASA representative in attendance.

V. APPENDIX

PAGE





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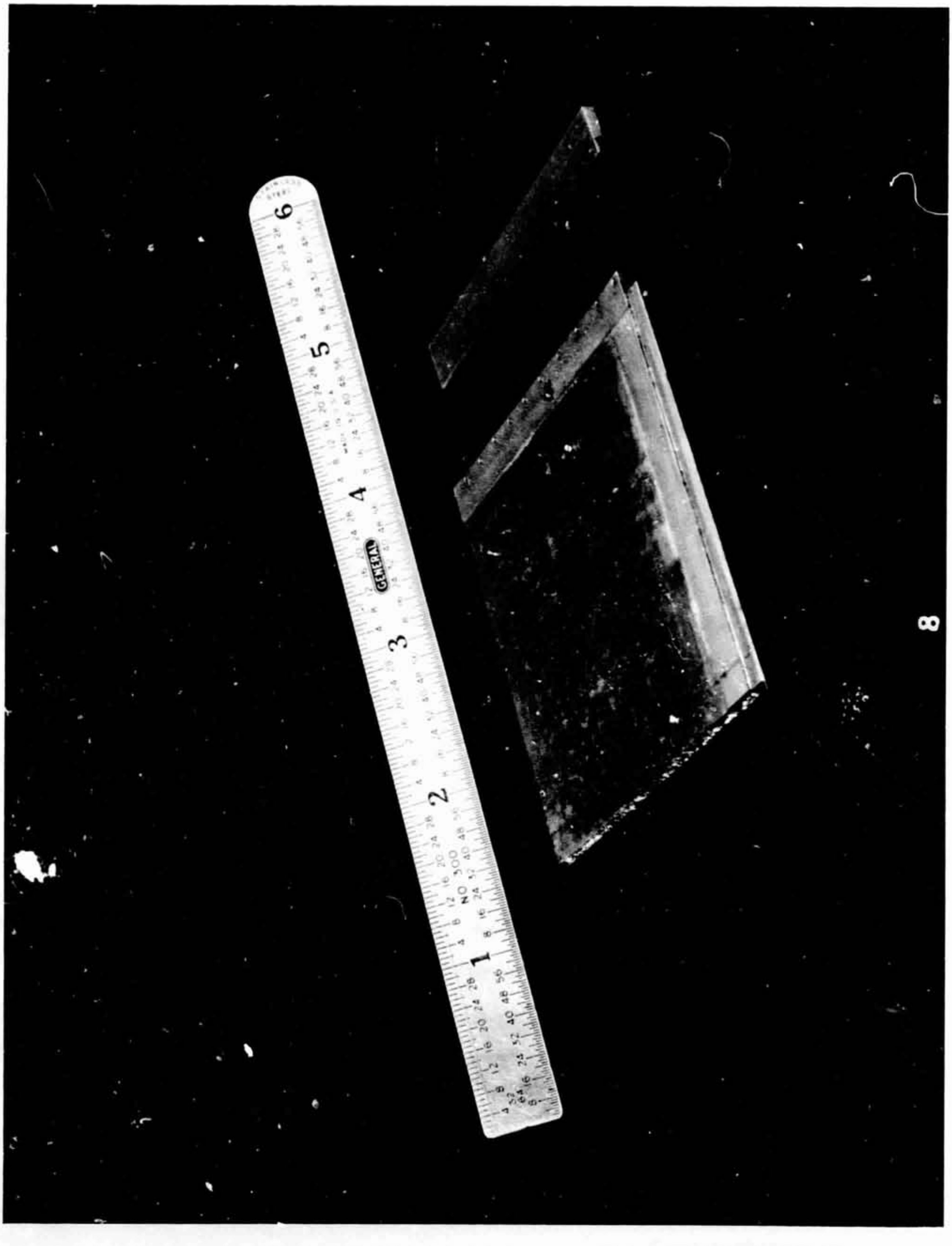
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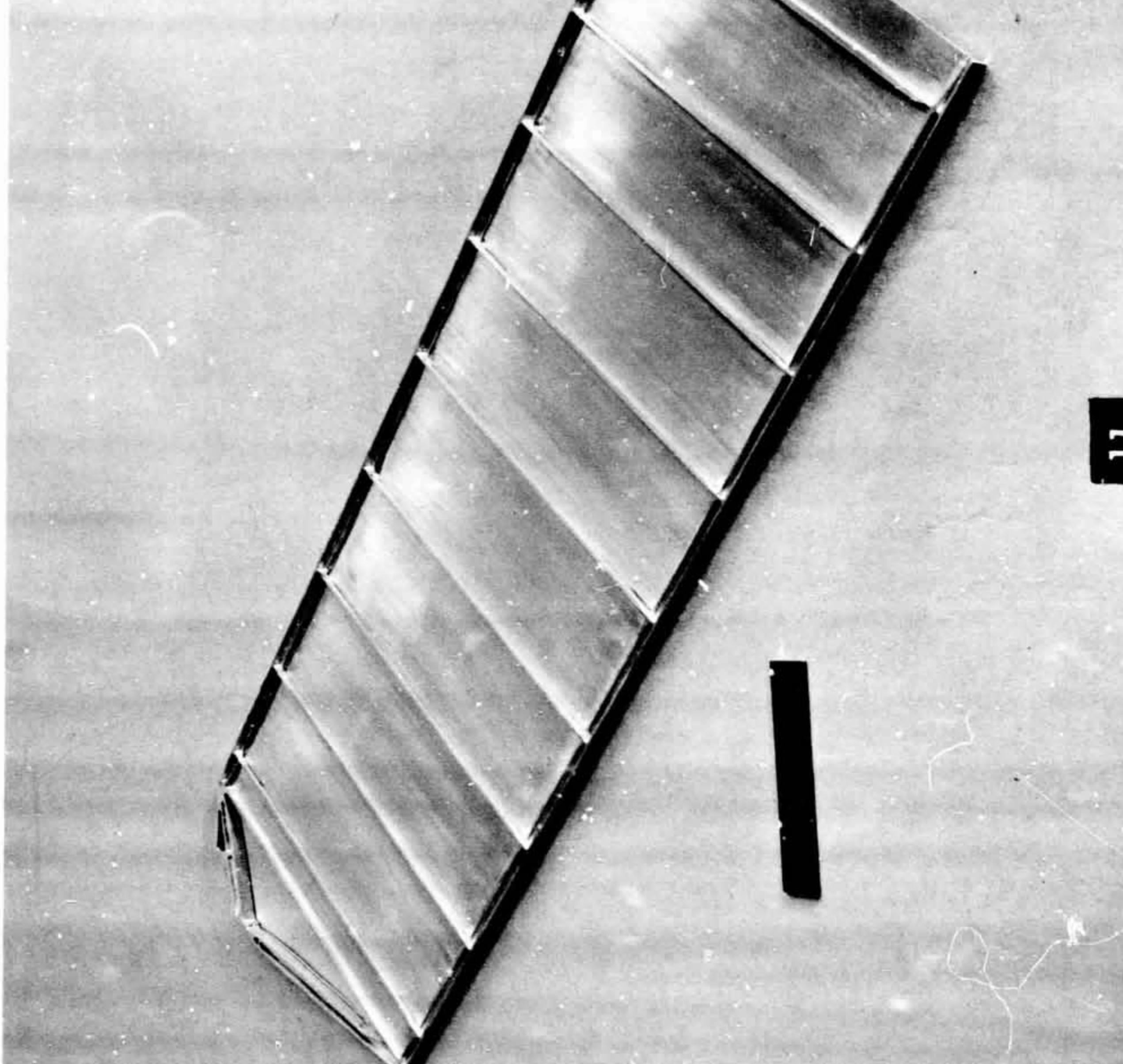

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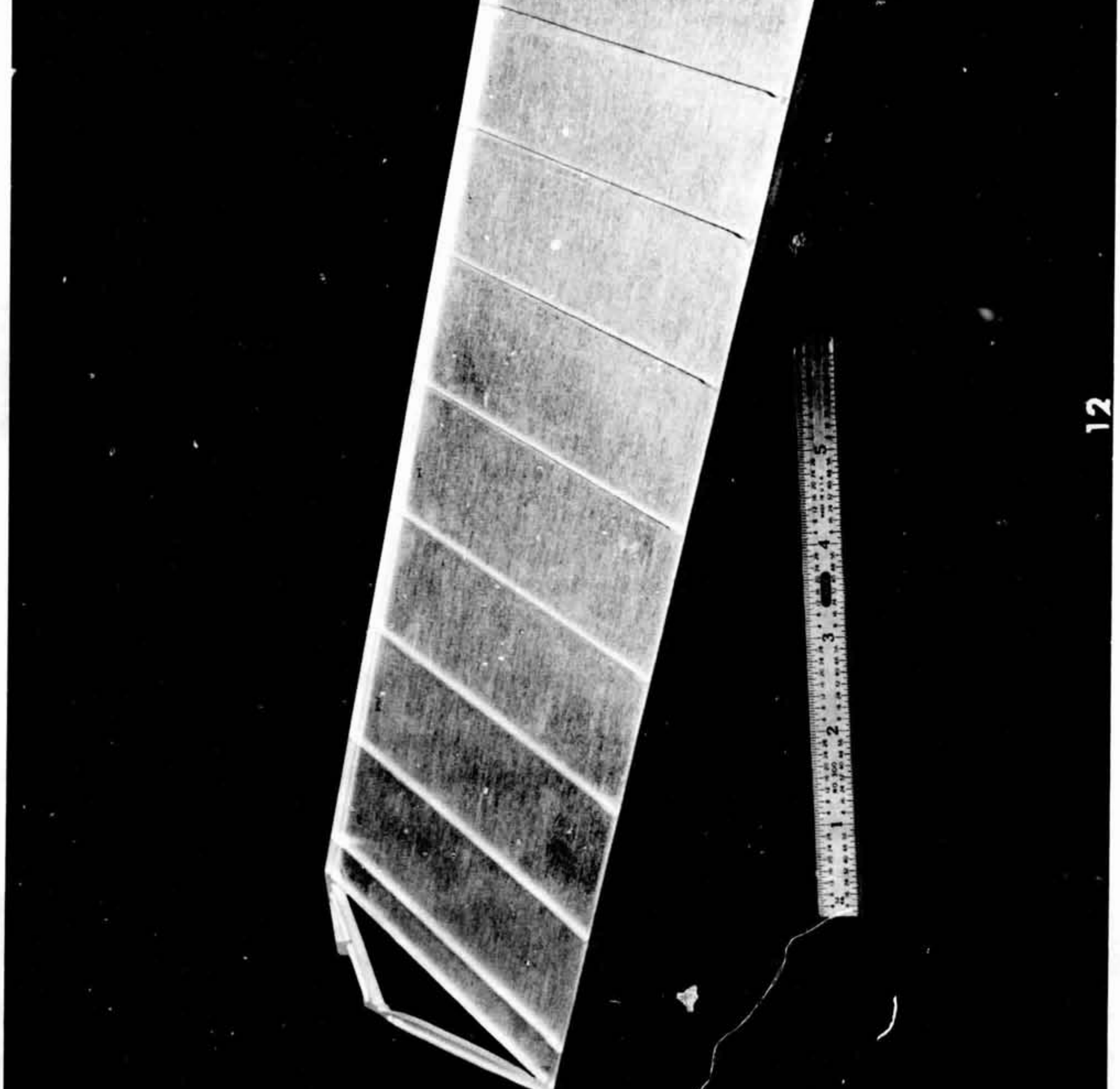
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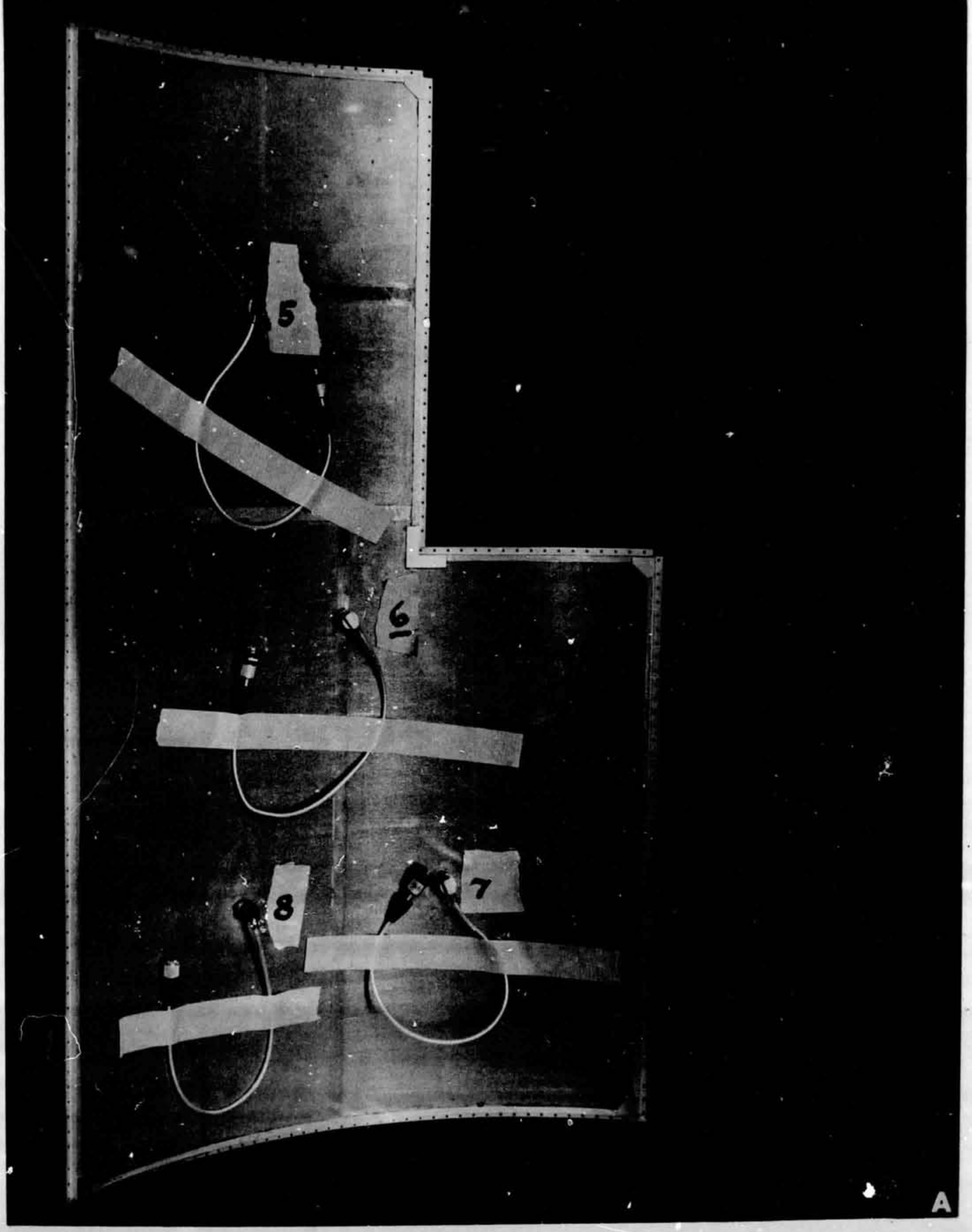
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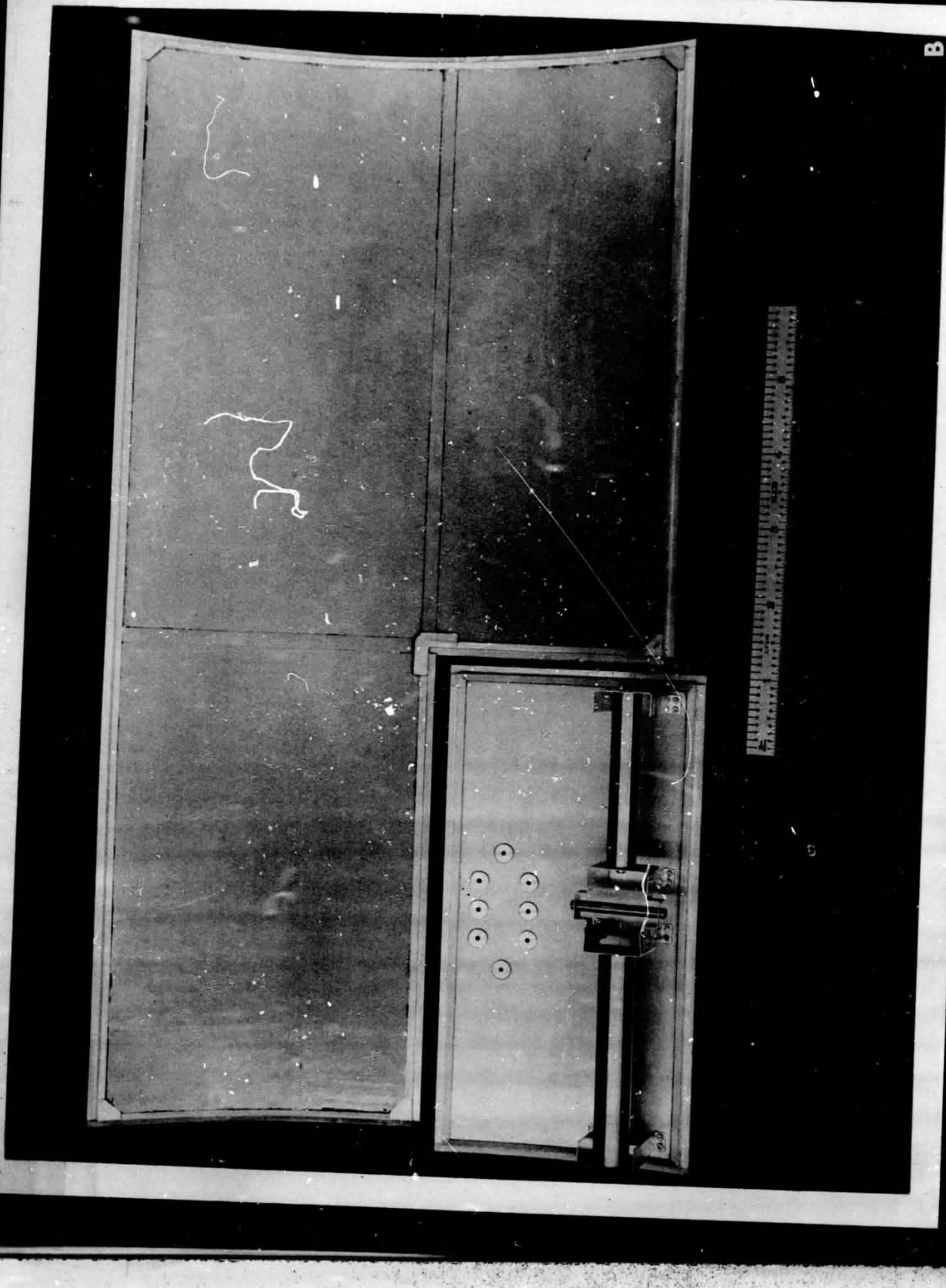
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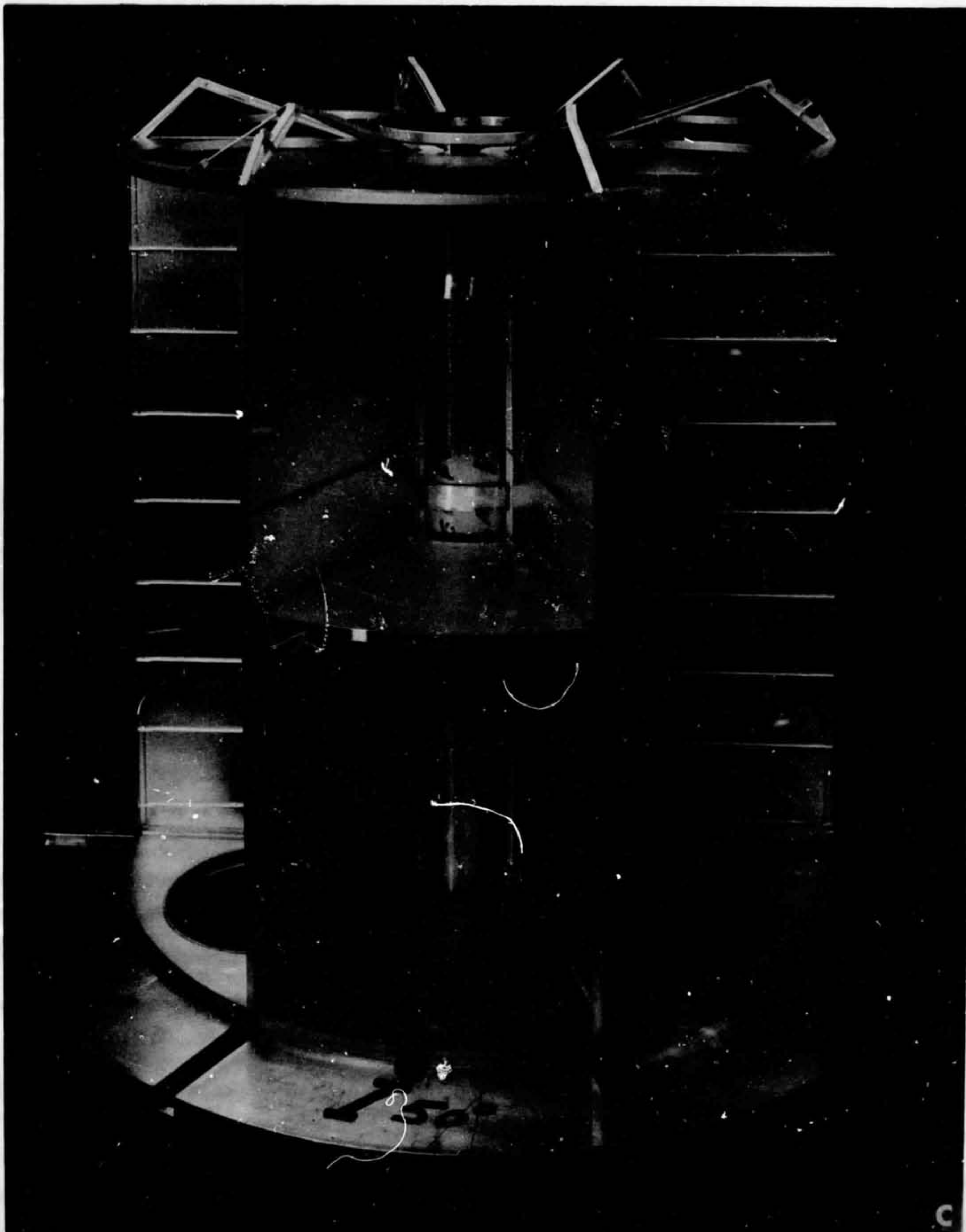
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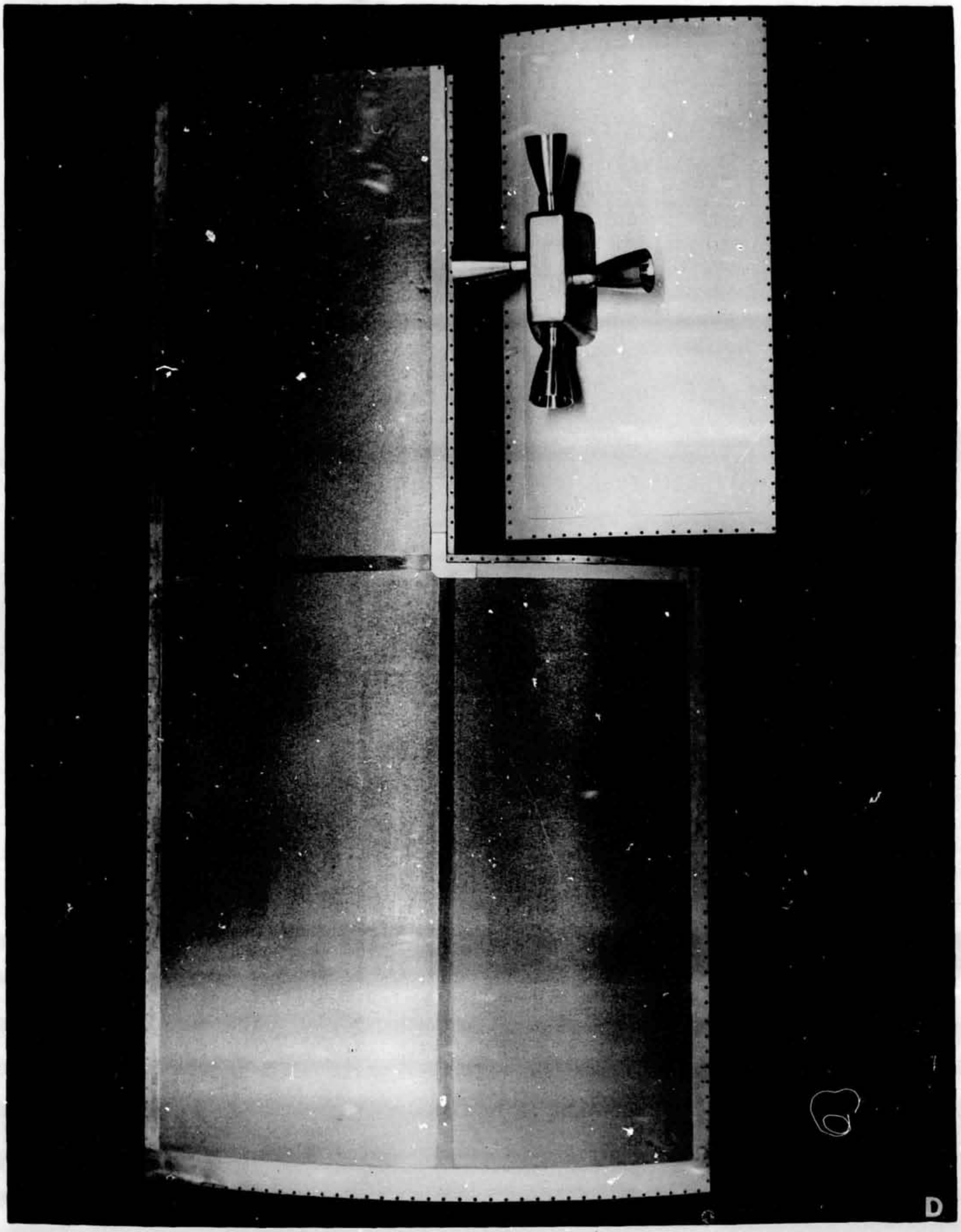
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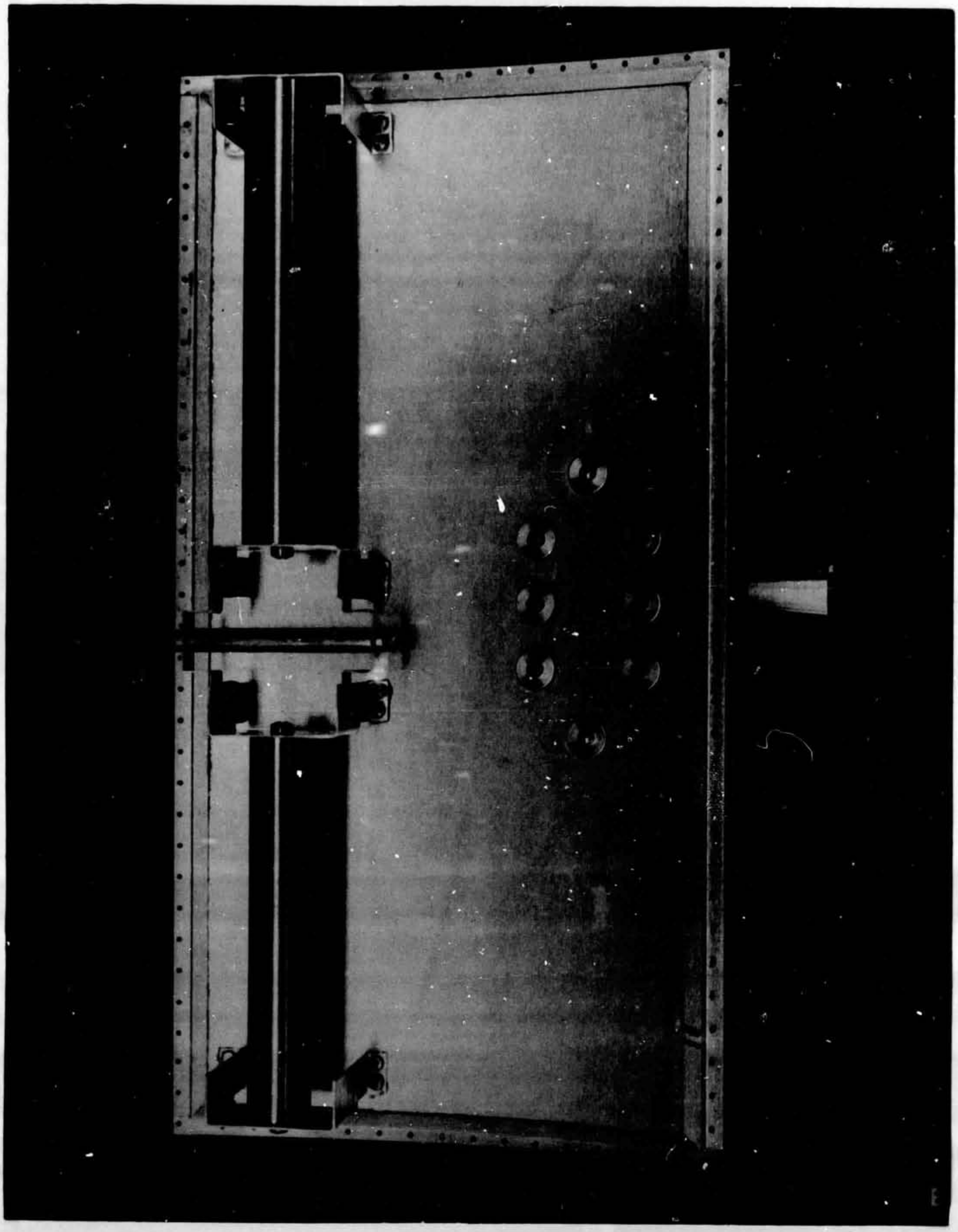

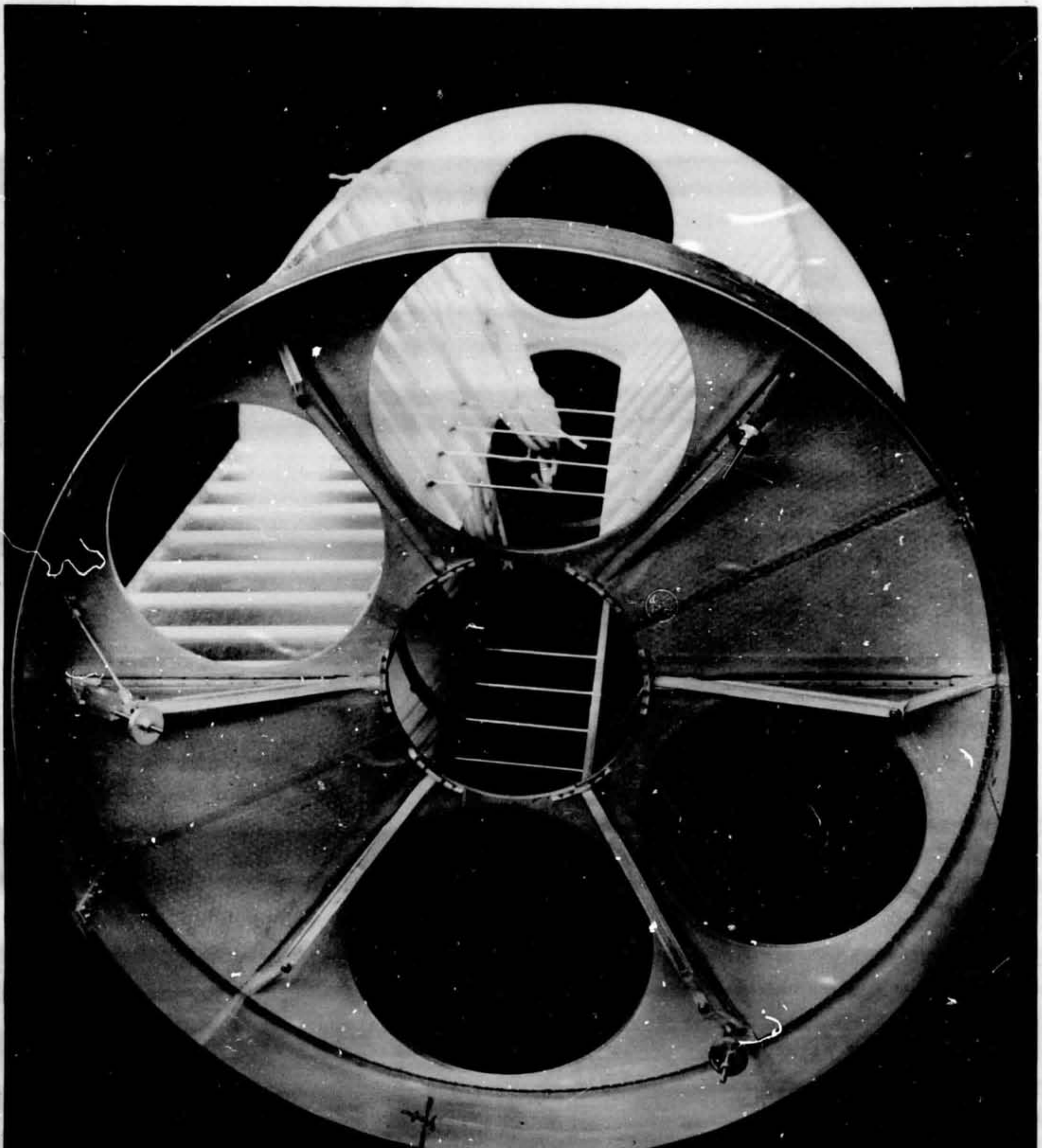
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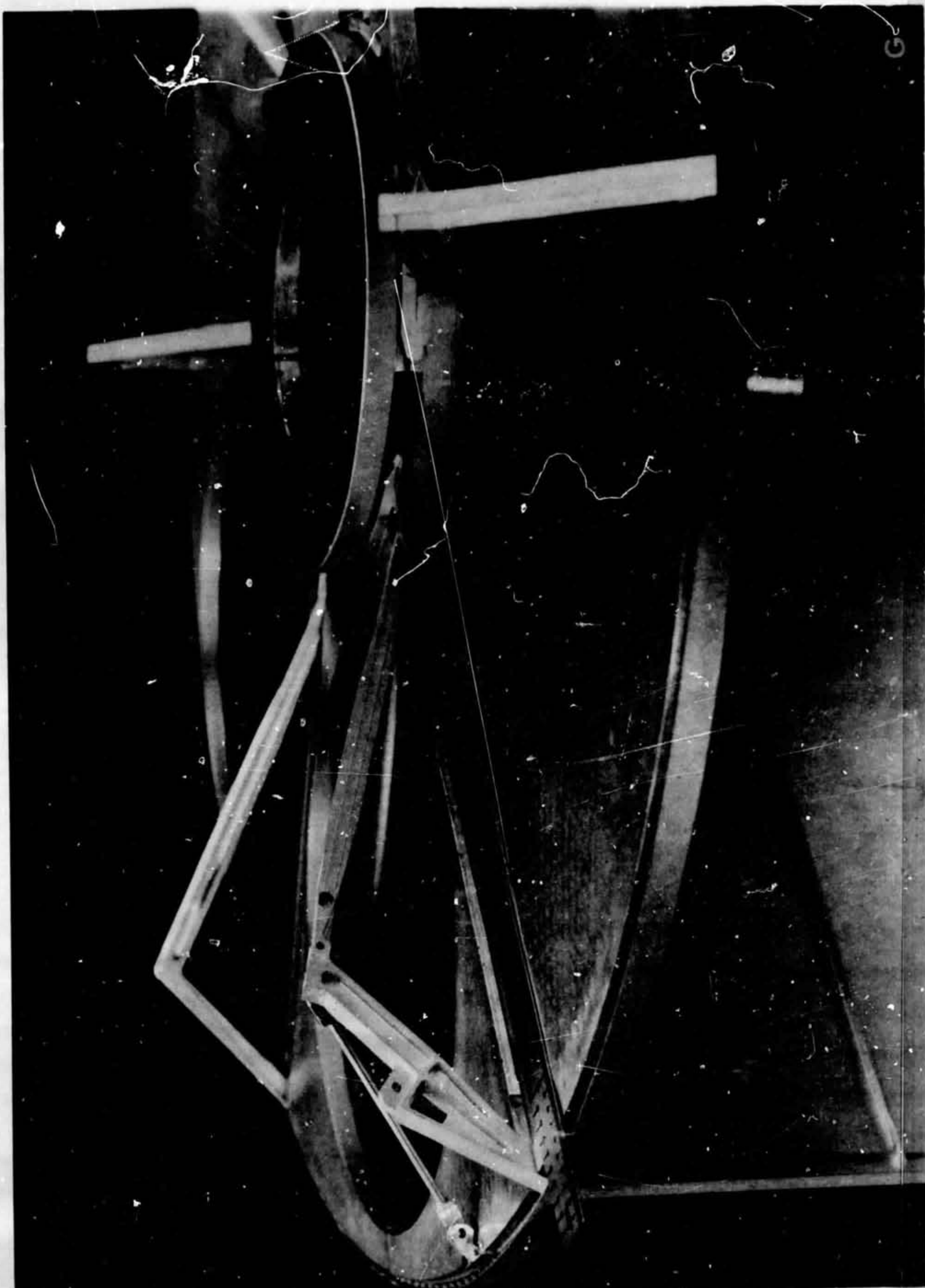
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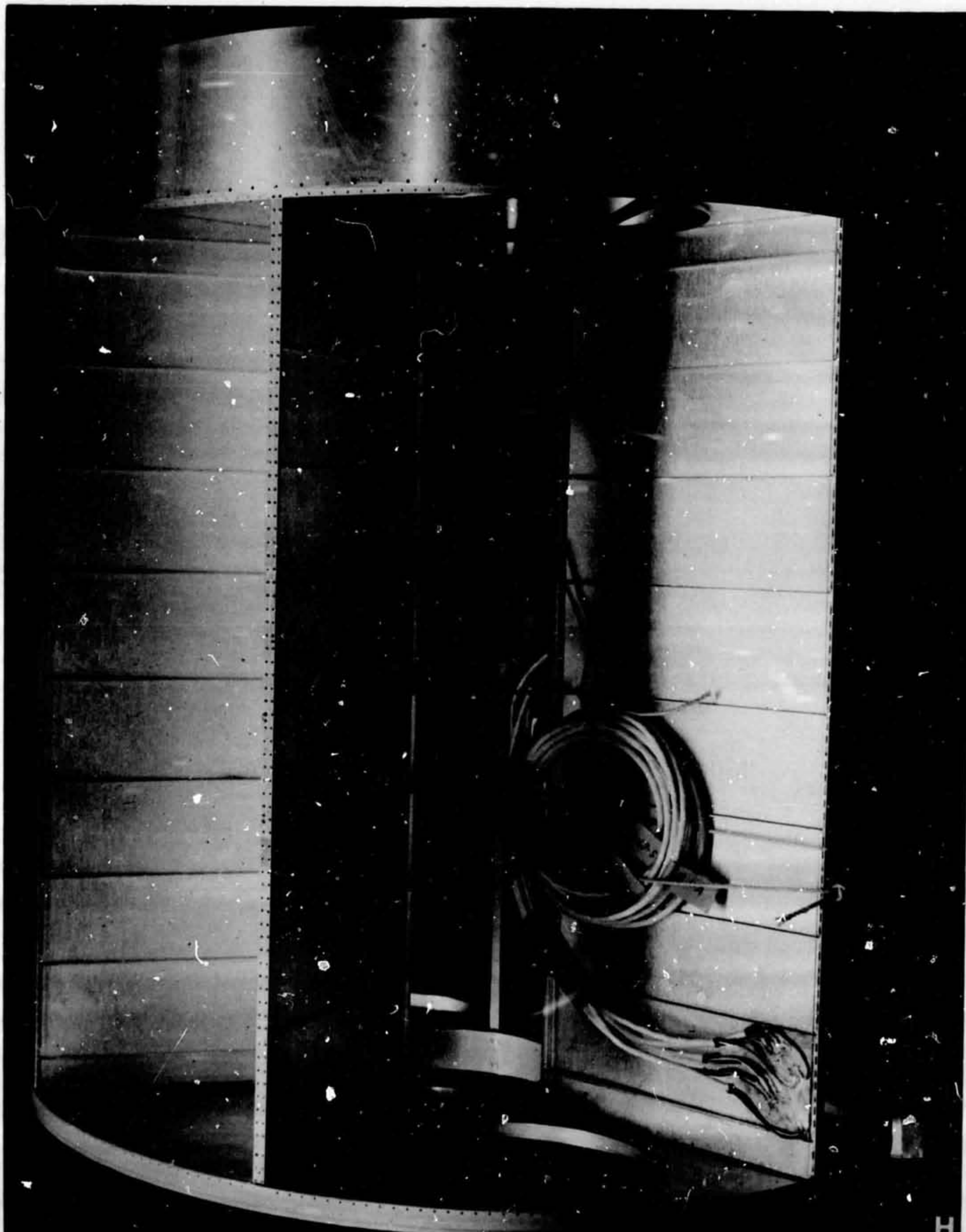
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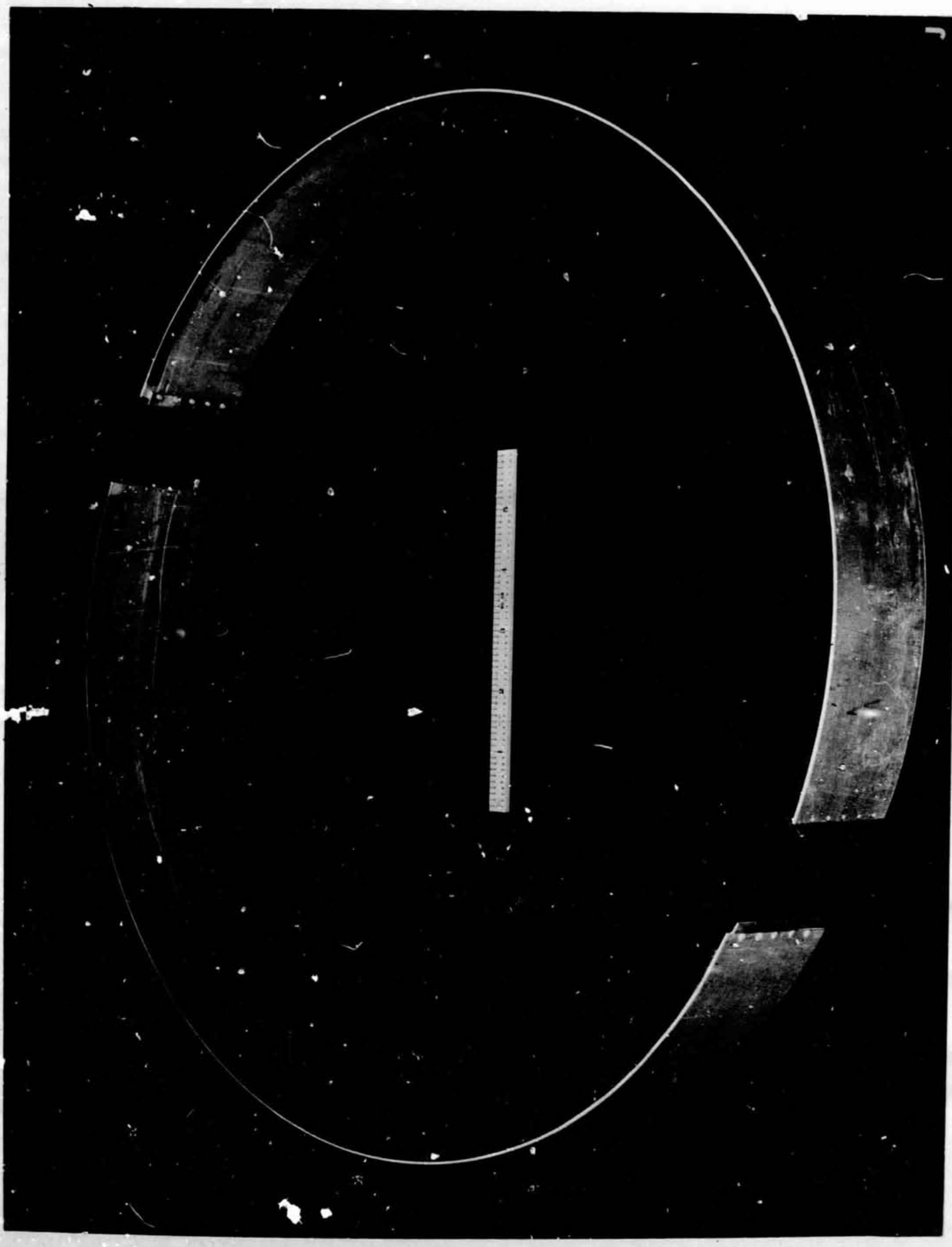

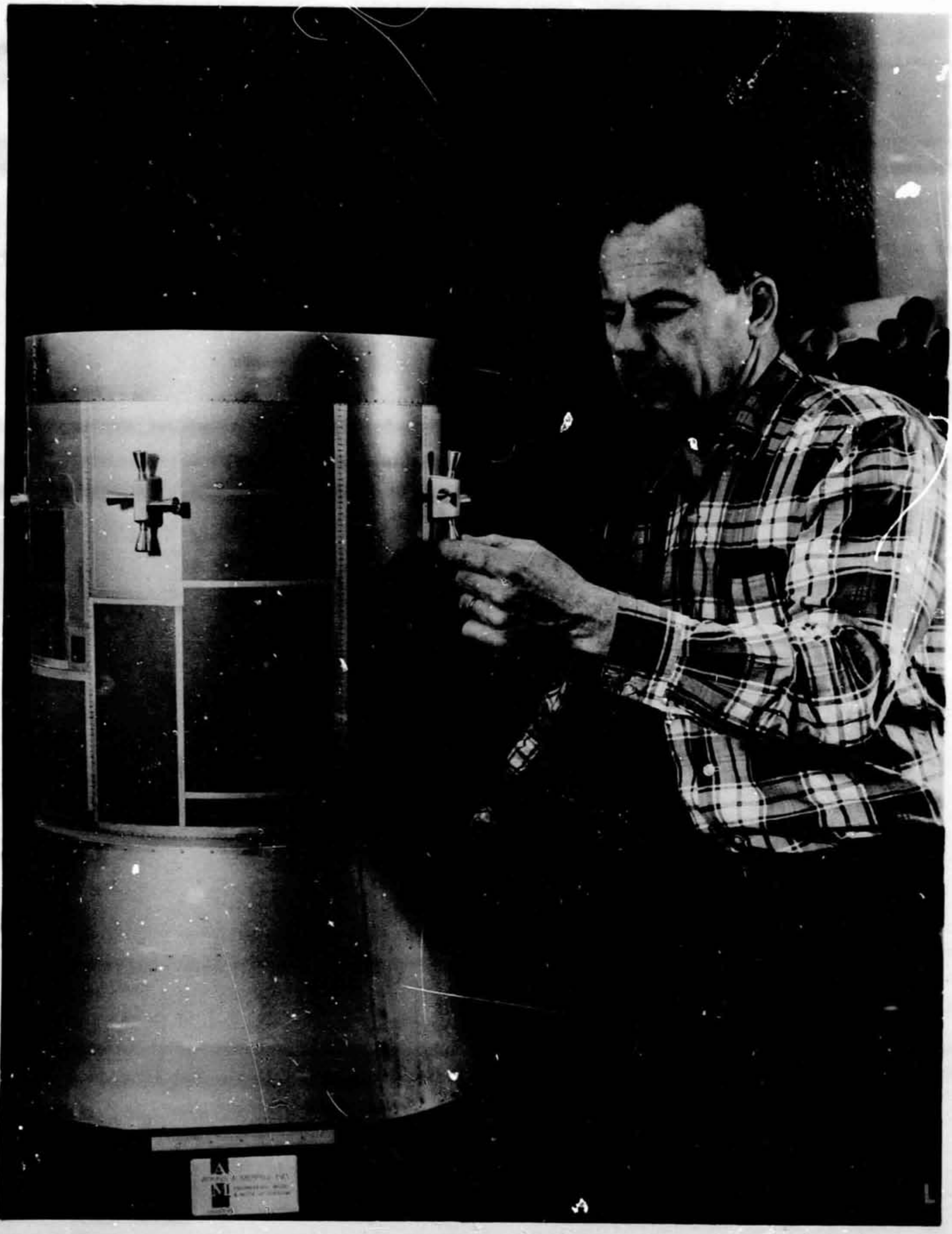

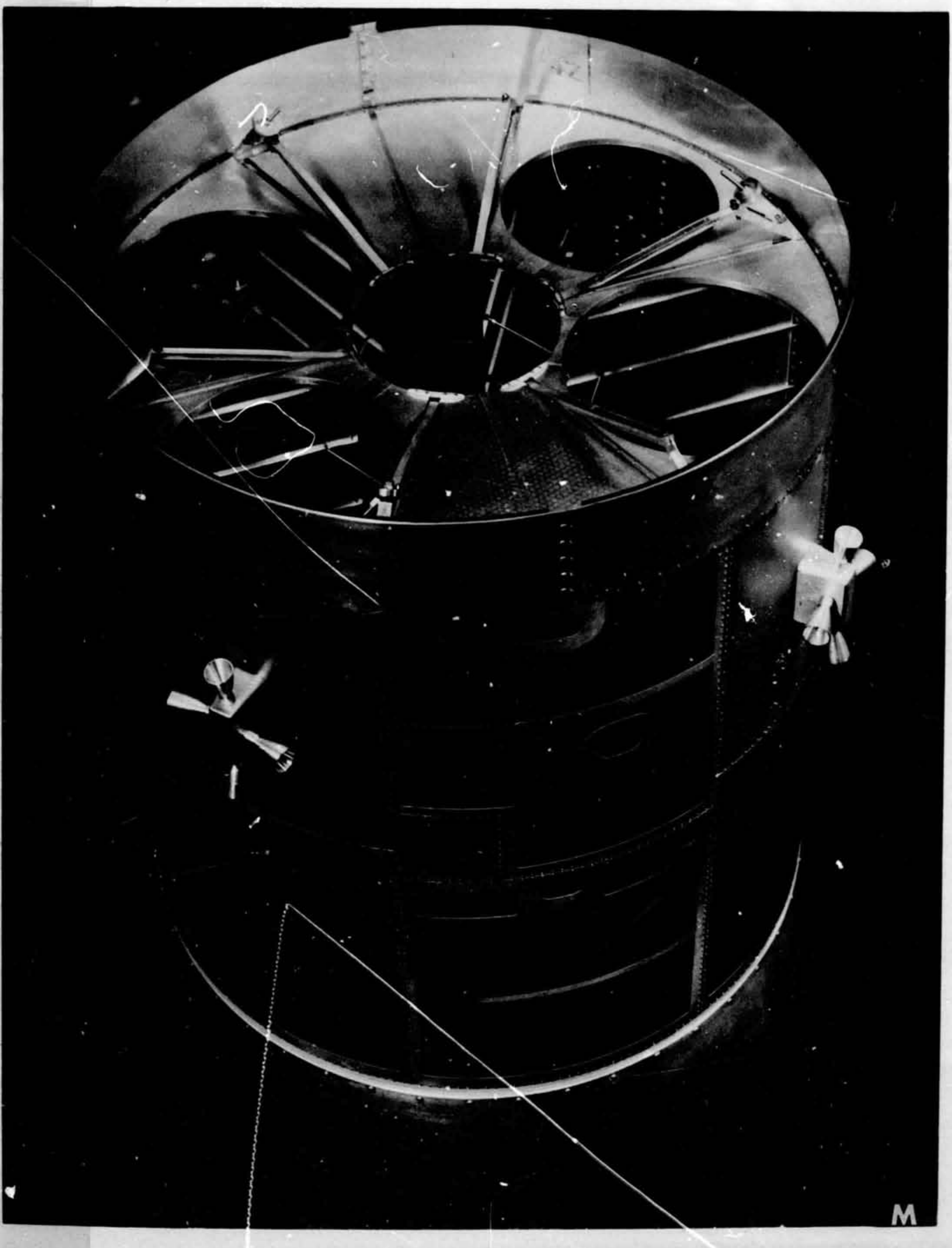
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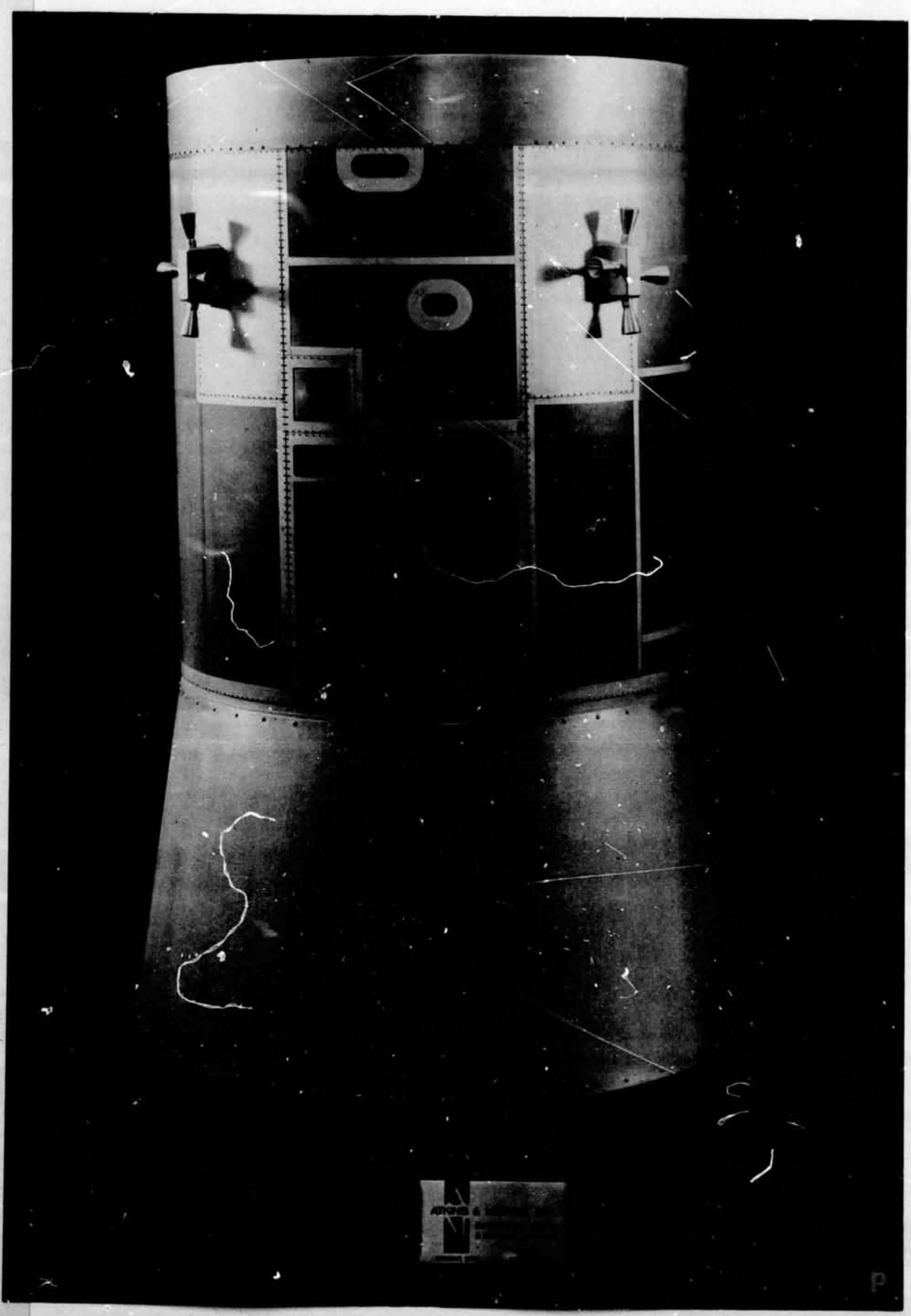

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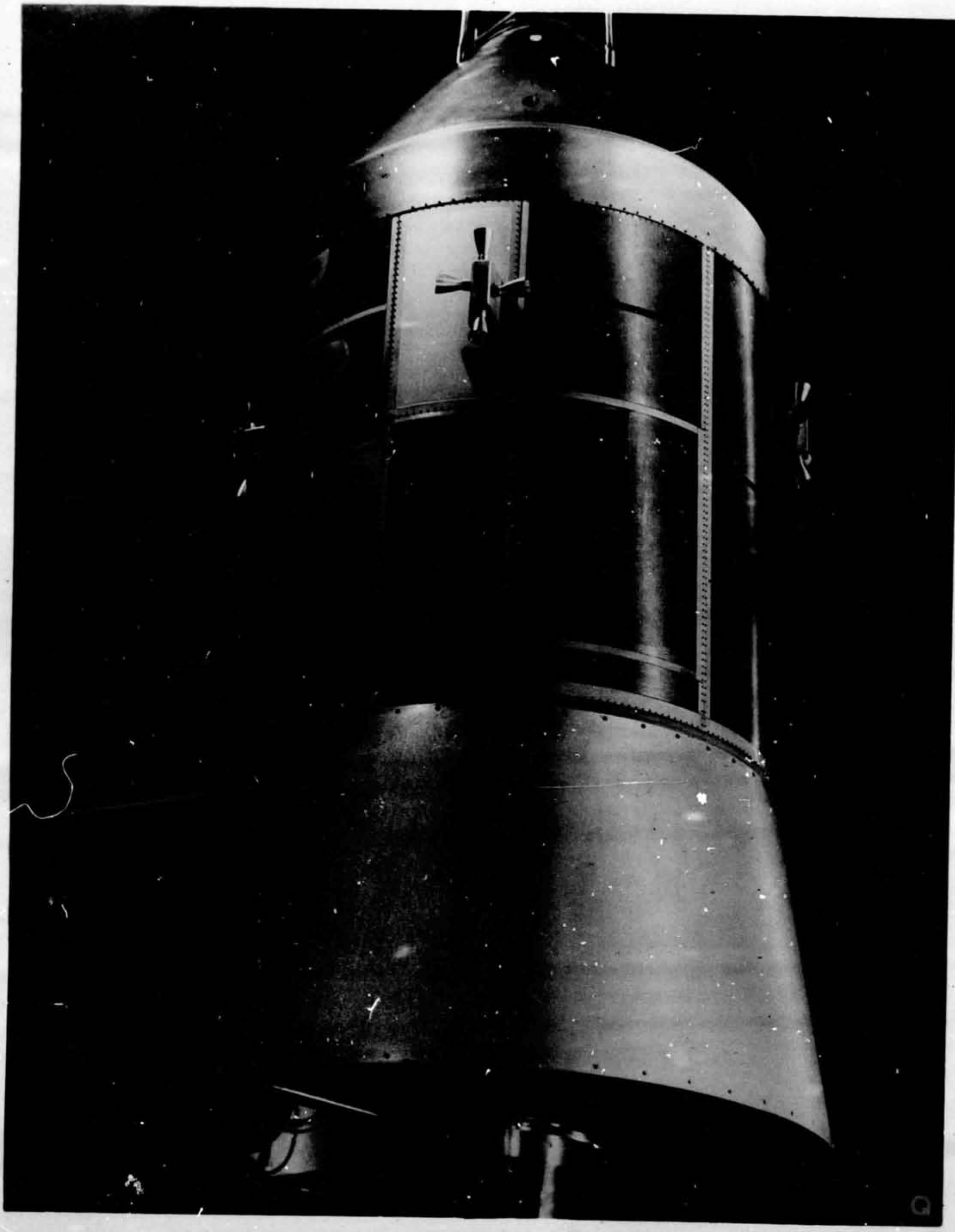

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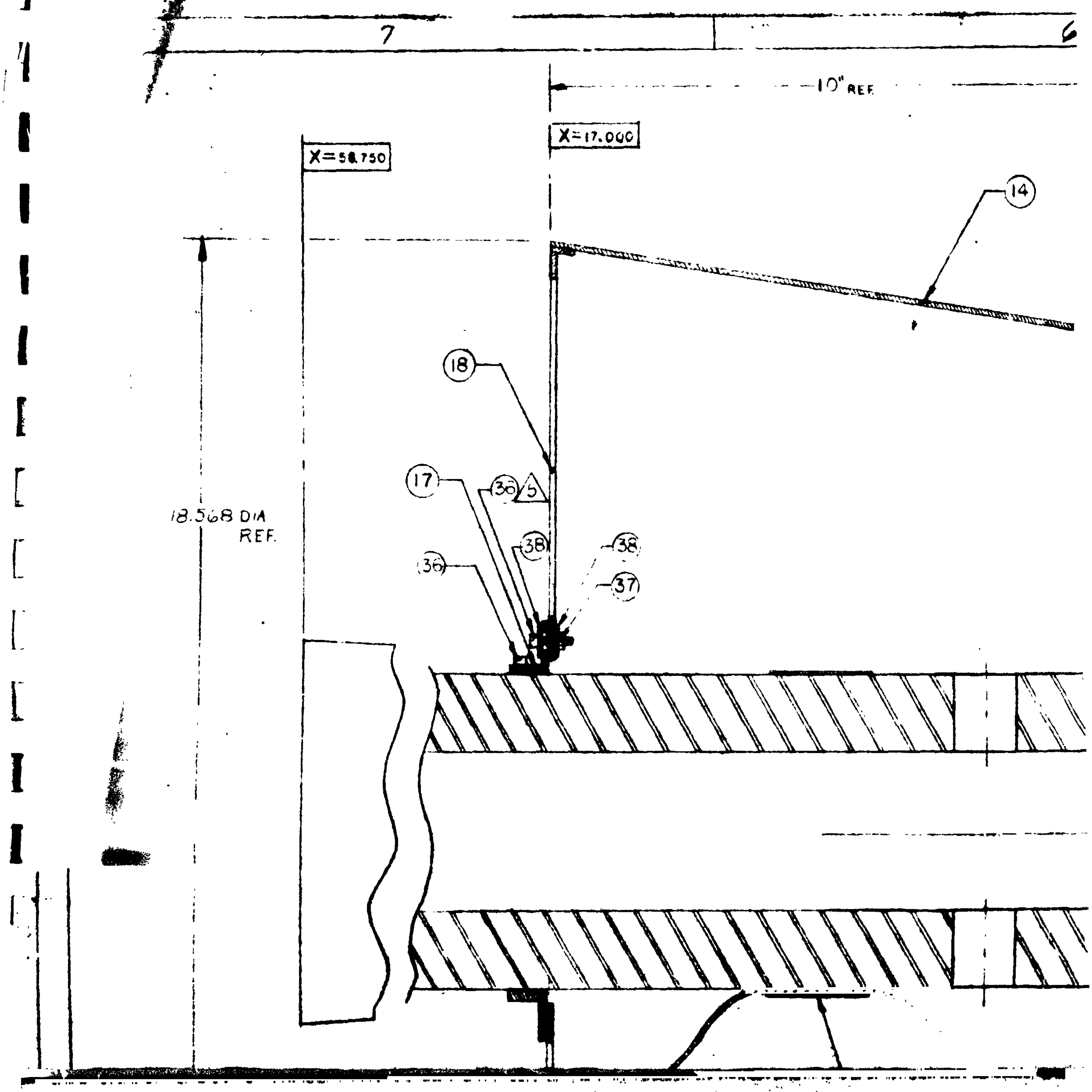

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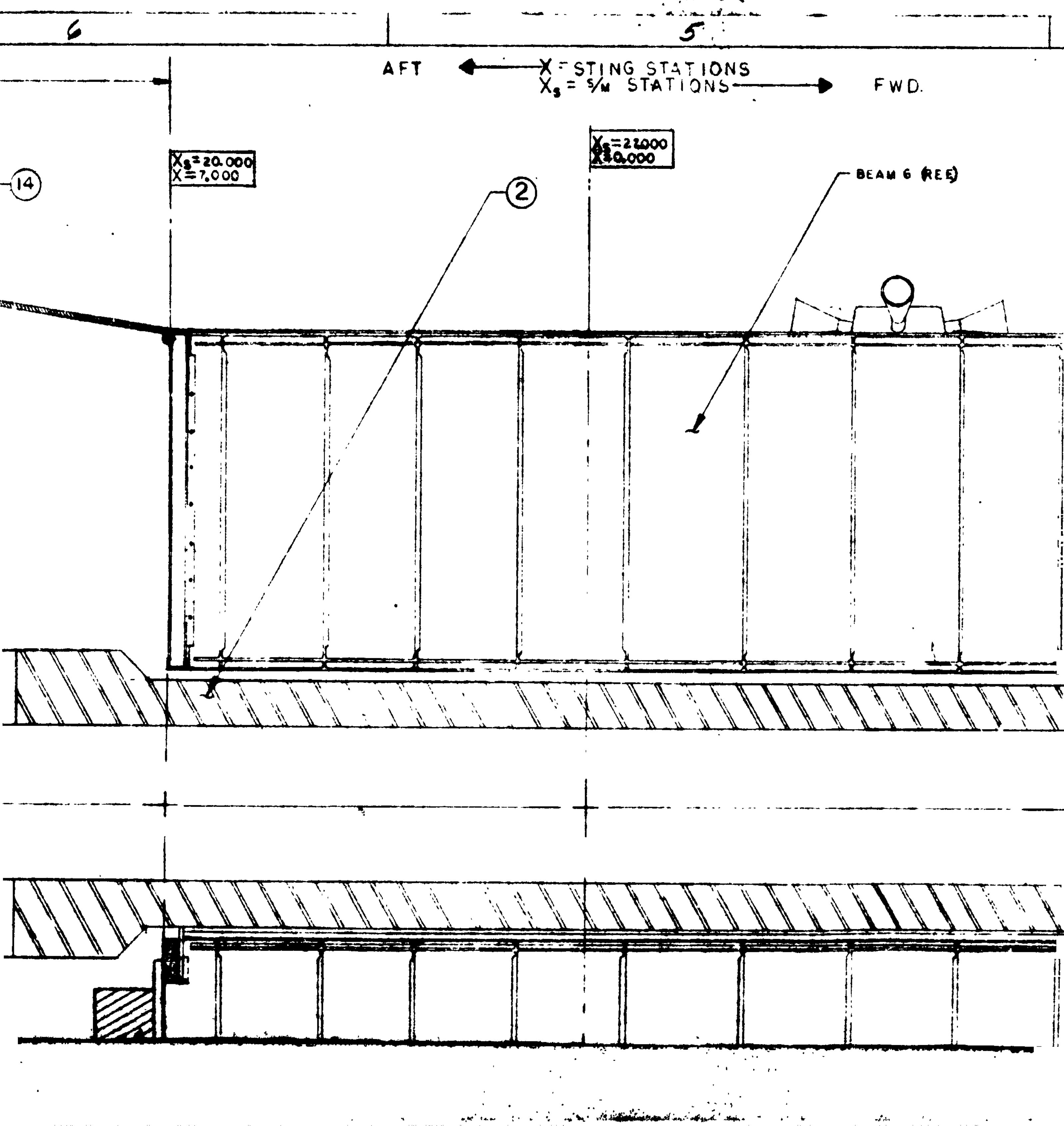

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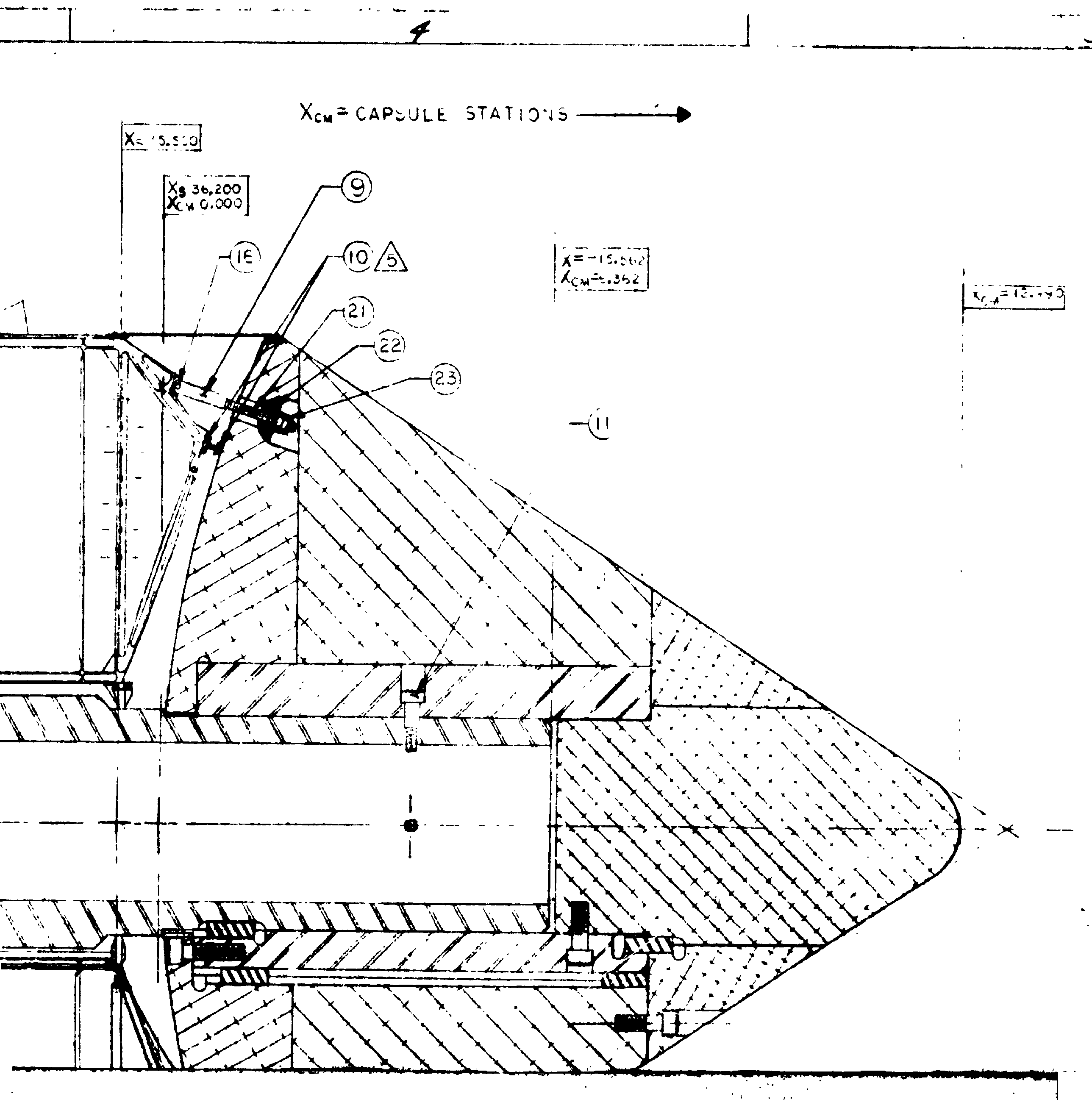

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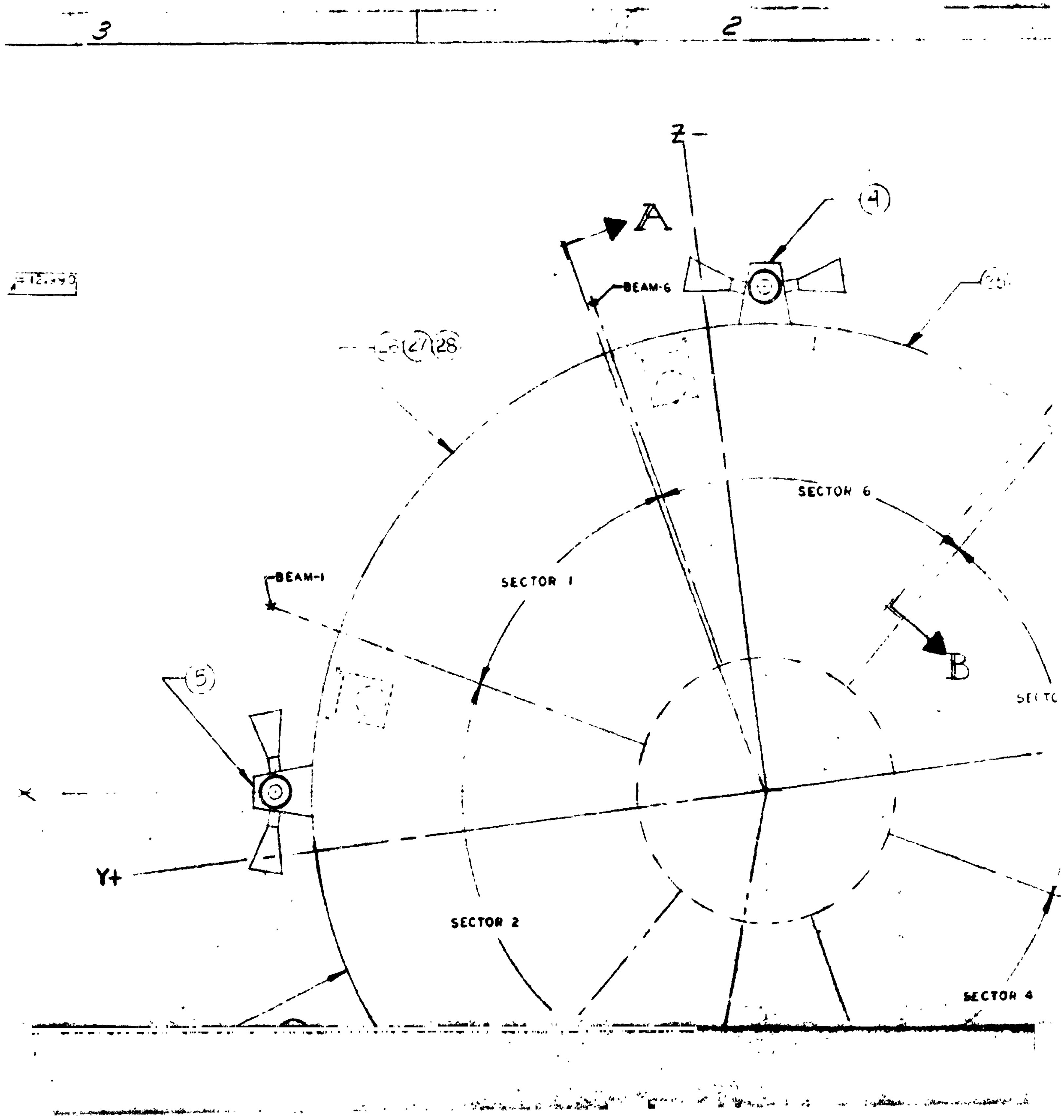

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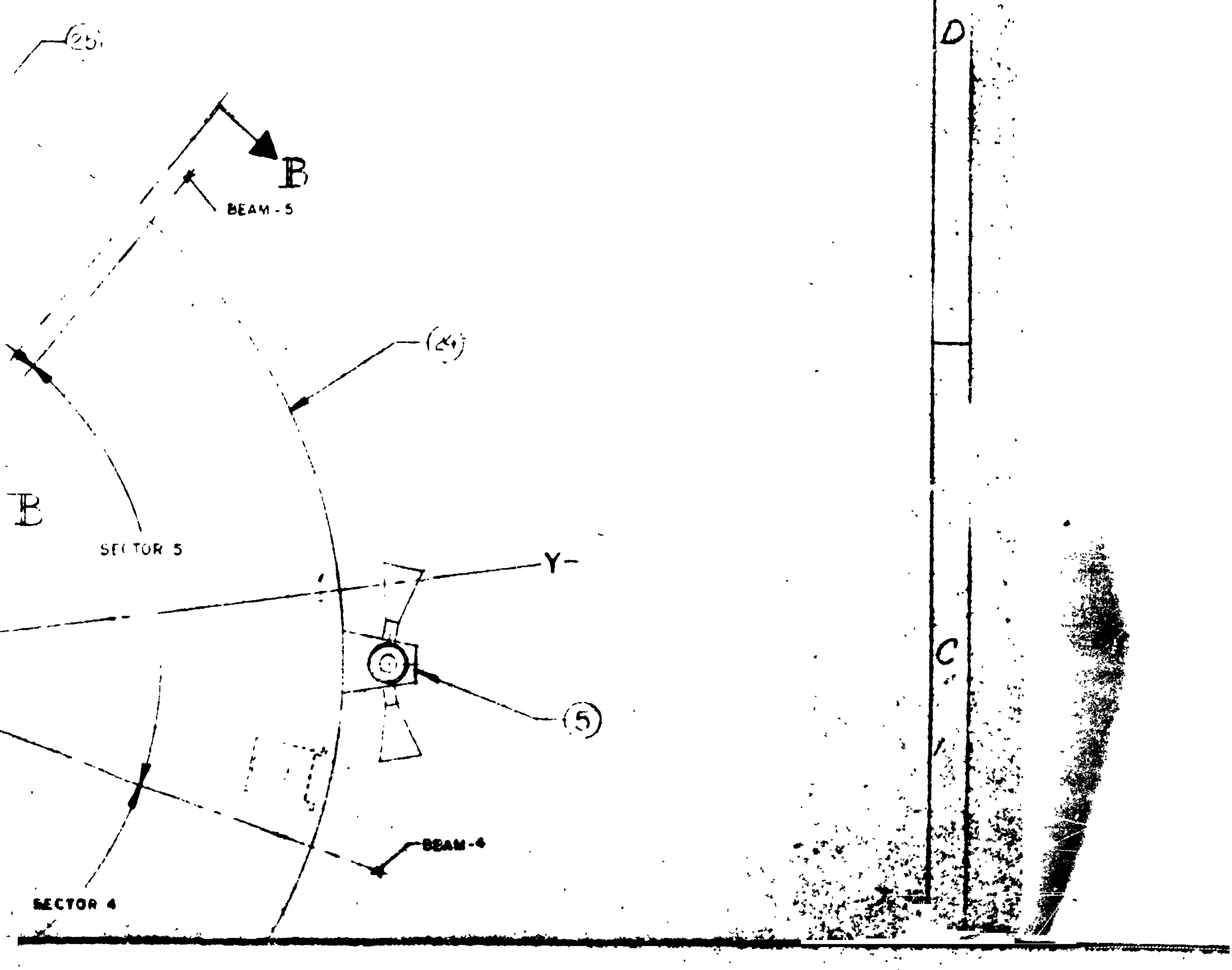

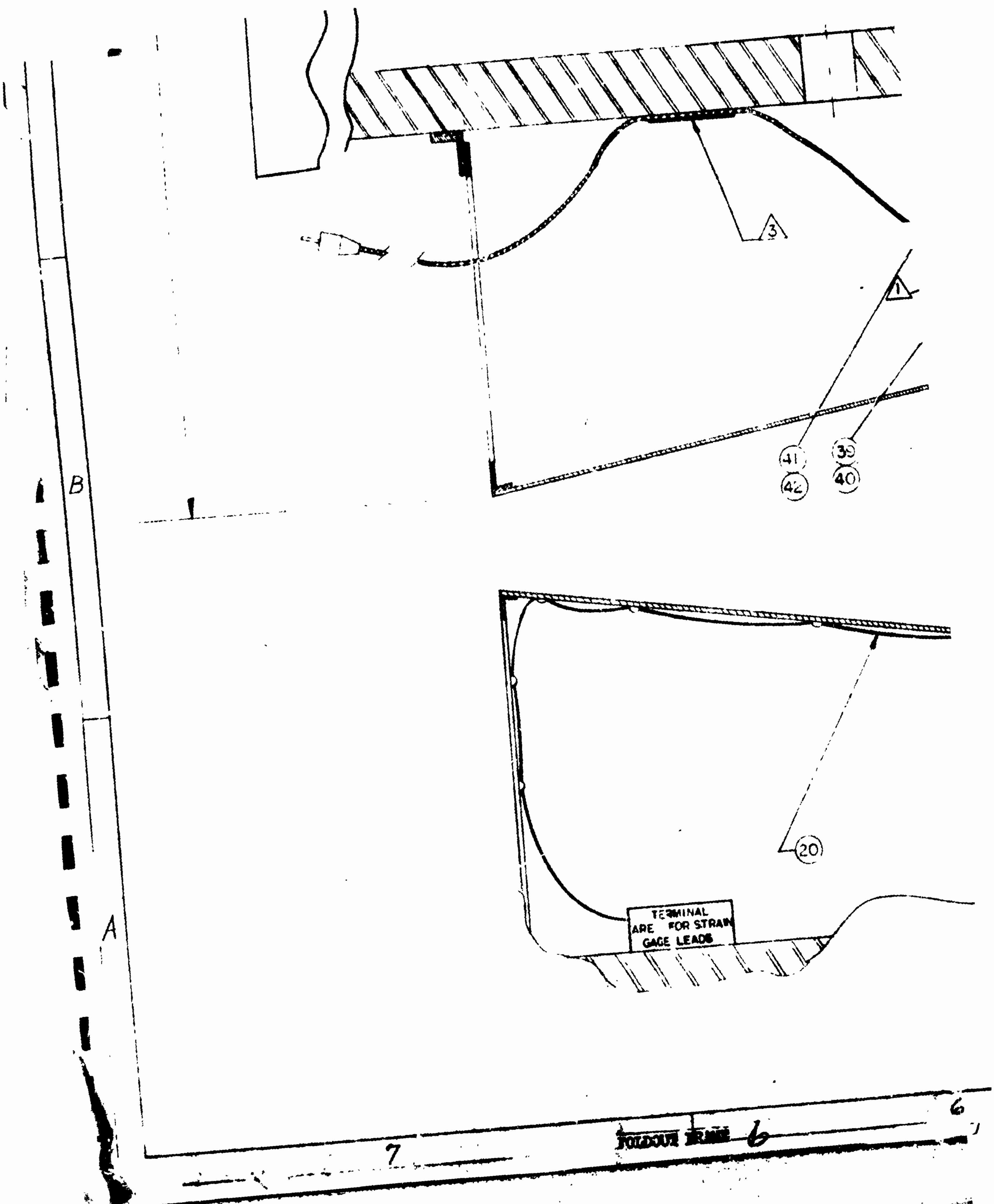

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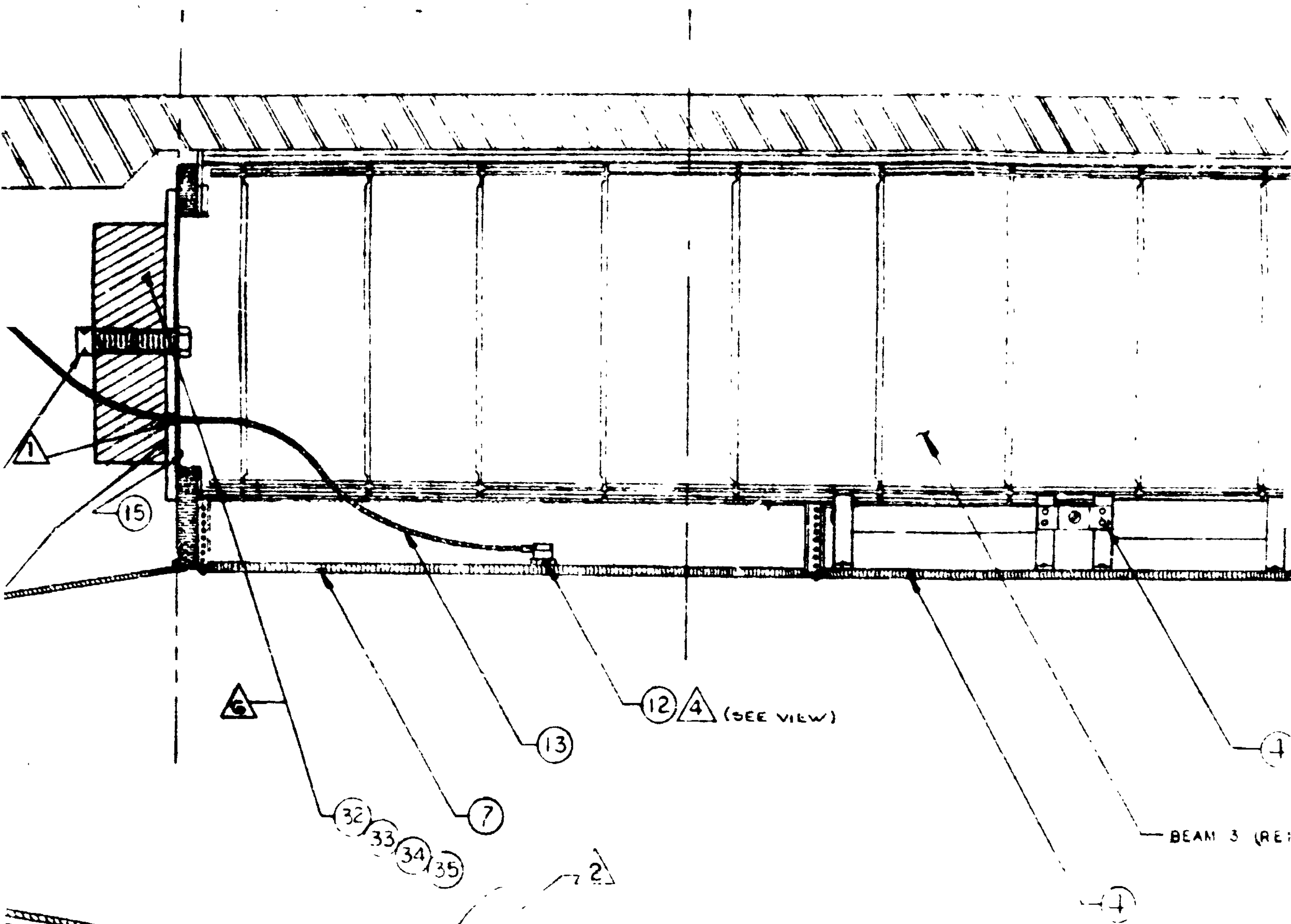

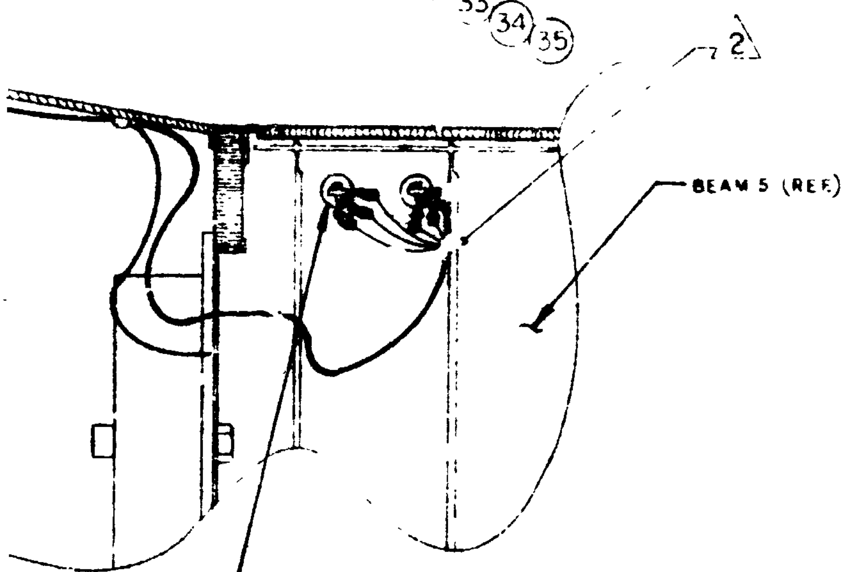

SECTION B-B

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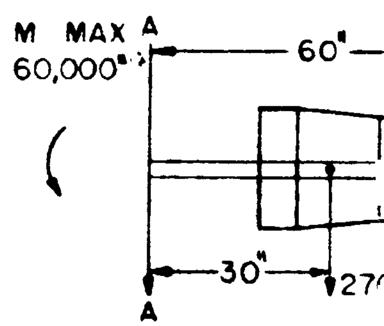

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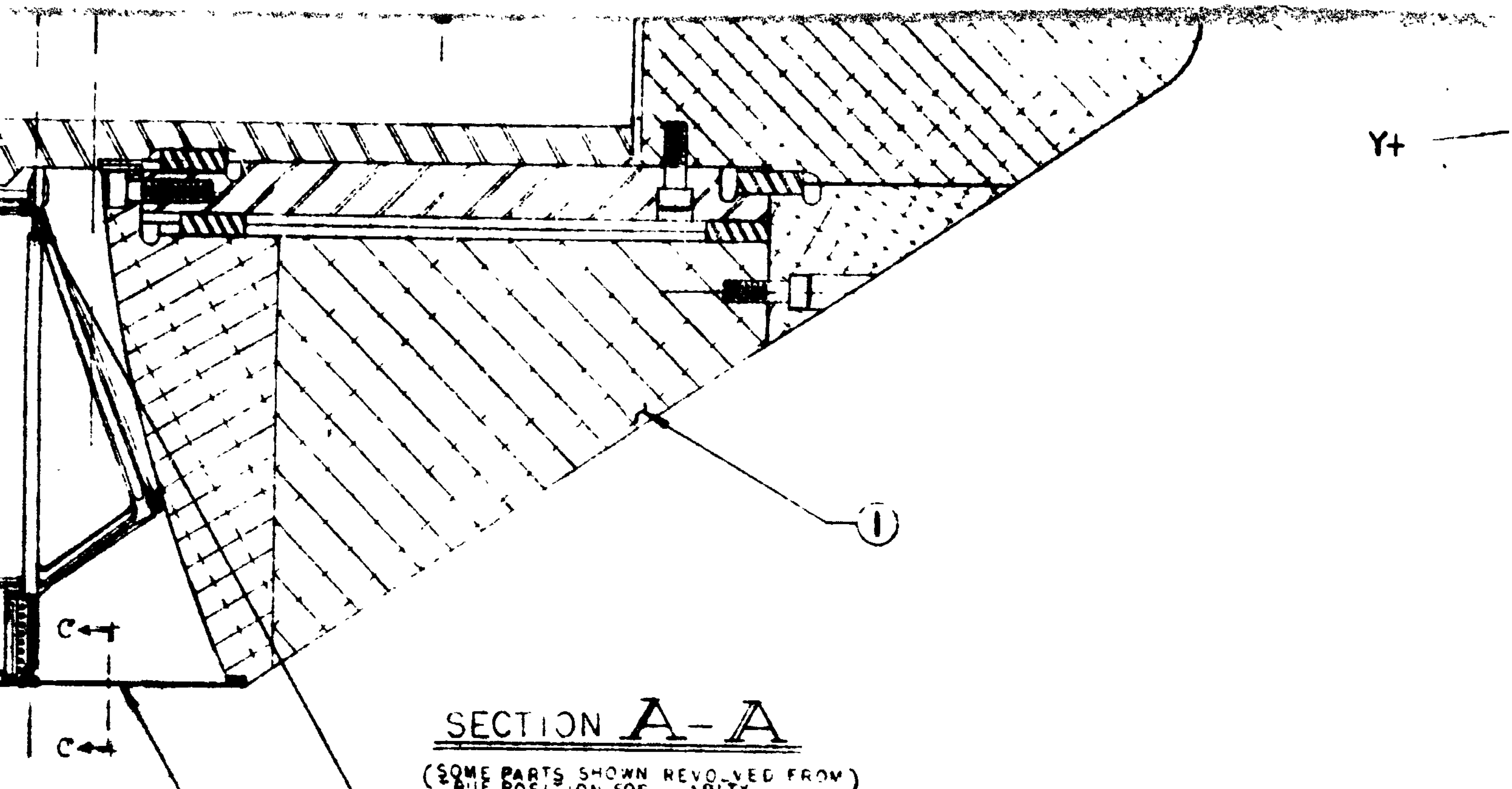

SECTION A-A

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SECTION C-C
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NOTES

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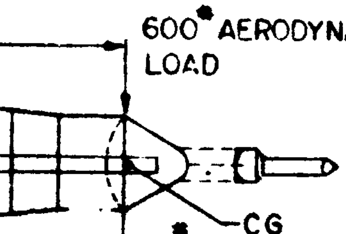

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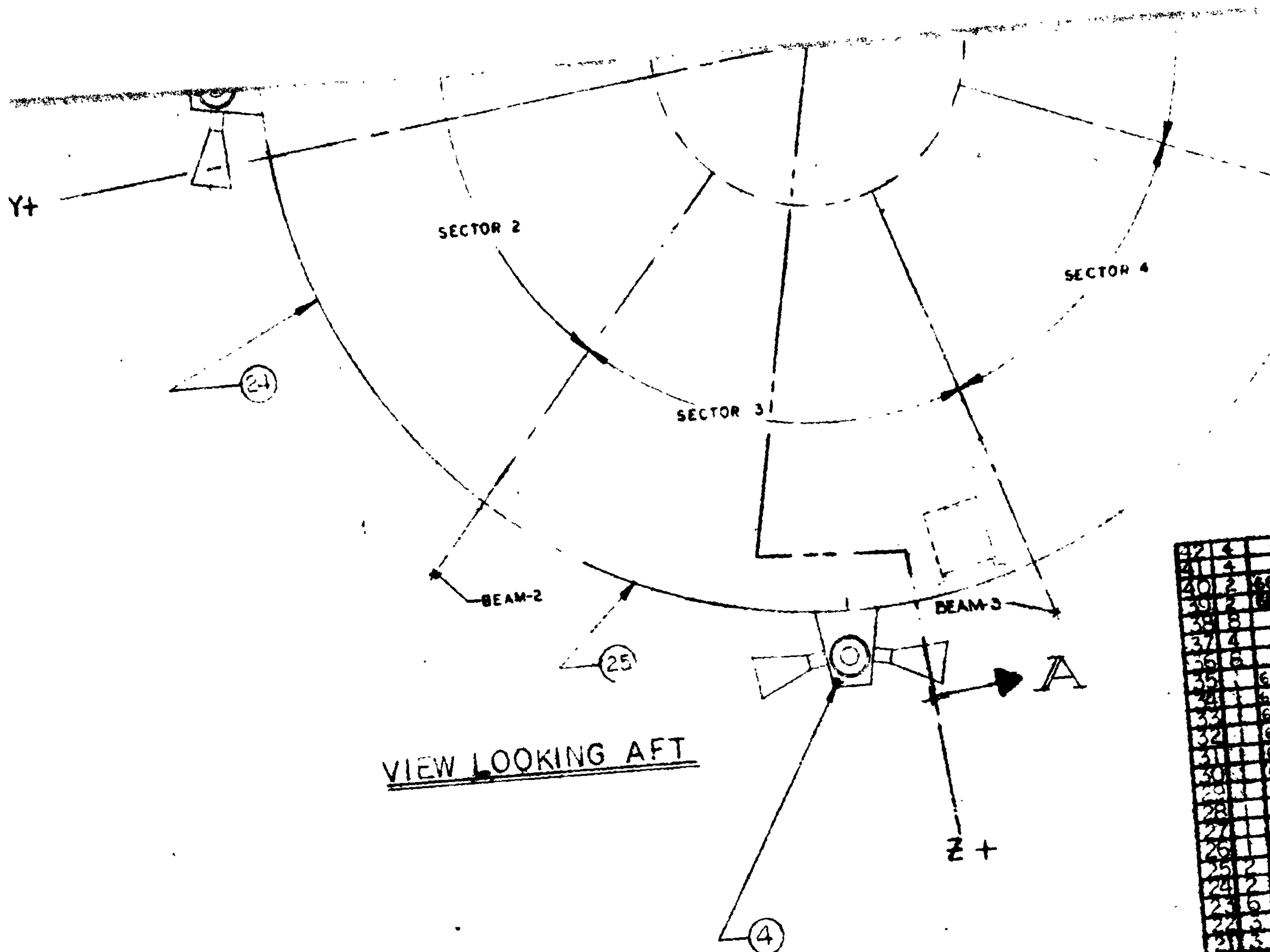

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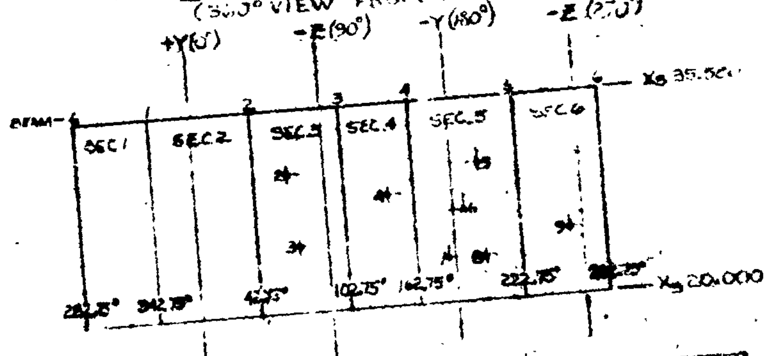

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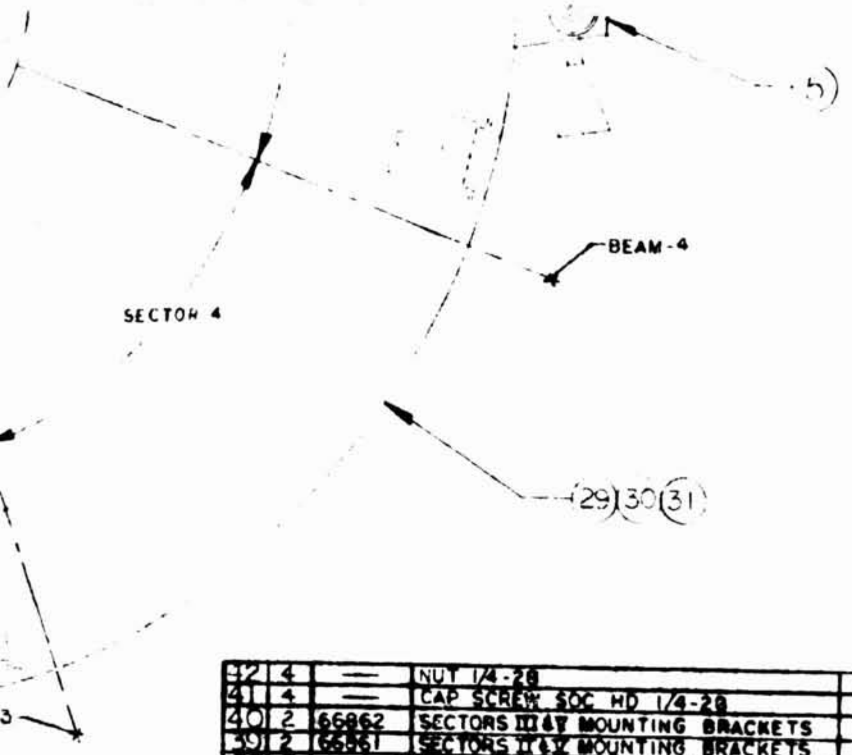


ITEM	QTY	PART NO	DESCRIPTION	MAT'L	MAT'L SPEC	SOURCE
42	4	—	NUT 1/4-20			
41	4	—	CAP SCREW SOC HD 1/4-20			
40	2	66862	SECTORS III & V MOUNTING BRACKETS			
39	2	66861	SECTORS II & V MOUNTING BRACKETS			
38	8	—	#4 FLAT WASHER			
37	[illegible]	—	#4-40 HEX NUTS			
36	6	—	#4-40 x .50 LG SOC HD CAP SC			
35	1	66856-5	WEIGHT BLOCK SECT 5			
34	1	66856-6	WEIGHT BLOCK SECT. 6			
33	1	66856-2	WEIGHT BLOCK SECT. 2			
32	1	66856-3	WEIGHT BLOCK SECT. 3			
31	1	66542	OUTER SHELL SECT 4 DOOR			
30	1	66535	OUTER SHELL SECT. 4 AFT.			
29	1	66528	OUTER SHELL SECT. 4 FWD.			
28	1	66545	OUTER SHELL SECT. 1 DOOR			
27	1	66554	OUTER SHELL SECT. 1 AFT.			
26	1	66550	OUTER SHELL SECT. 1 FWD.			
25	2	66390	OUTER SHELL SECT. 3 & 6			
24	2	66393	OUTER SHELL SECT. 2 & 5			
23	6	—	#2-56 HEX NUTS			
22	3	—	SPHERICAL WASHER			
21	3	—	#2-56 x 1.50 LG THD ROD			
20	12	66960	STRAIN GAGE LEADS 26 STR SHLD 3 COND		12-B	W. T. BEAN INC.
19	24	66960	STRAIN GAGE		CL3 R345E STK	DENTRONICS INC.
18	1	[illegible]	LEM CONE SUPPORT			
17	1	66857	LEM CONE SUPPORT RING			
16	[illegible]	—	CLEVIS PIN - .062 DIA.			
15	42	—	#0-80 x .19 LG. SOC. HD. CAP SC.			
14	1	66853	LEM CONE FAIRING			
13	8	—	ACCELEROMETER CABLE		LN-3	NASA.
12	8	—	ACCELEROMETER		606-2	NASA.
11	2	—	SHOULDER SCREW .25 DIA. - .38 LG. 10-24 THD			
10	6	—	ALIGNMENT SC. #1-72 X .50 LG RD HD.			
9	3	66380	CLEVIS-MODULE ATTACHMENT			
8	1	66383	S/M FAIRING			
7	2	66399	PANEL-SHELL-TYP SECT. 3 & 6			
6	10	—	#0-80 X .18 LG — OVAL FILL. HD. SC.			
5	2	66836	-6-2 R.C.S. PANEL ASS'Y			
4	2	66836	-6-1 R.C.S. PANEL ASS'Y			
3	1	66830	SERVICE MODULE-INTERNAL ASS'Y			
2	1	[illegible]	STING			
1	1		CAPSULE ASSEMBLY			NASA P/N 507654

LIST OF MATERIALS OR PARTS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES .X .XX .XXX ANGLES

DO NOT SCALE DRAWING

ATHENS [illegible] ENGINEERING MODEL & MOCKUP DIVISION

TITLE 1/10 SCALE APOLLO DYNAMIC MODEL ASSEMBLY

JOB NO 2411

CUSTOMER NASA-M-C

SCALE FULL

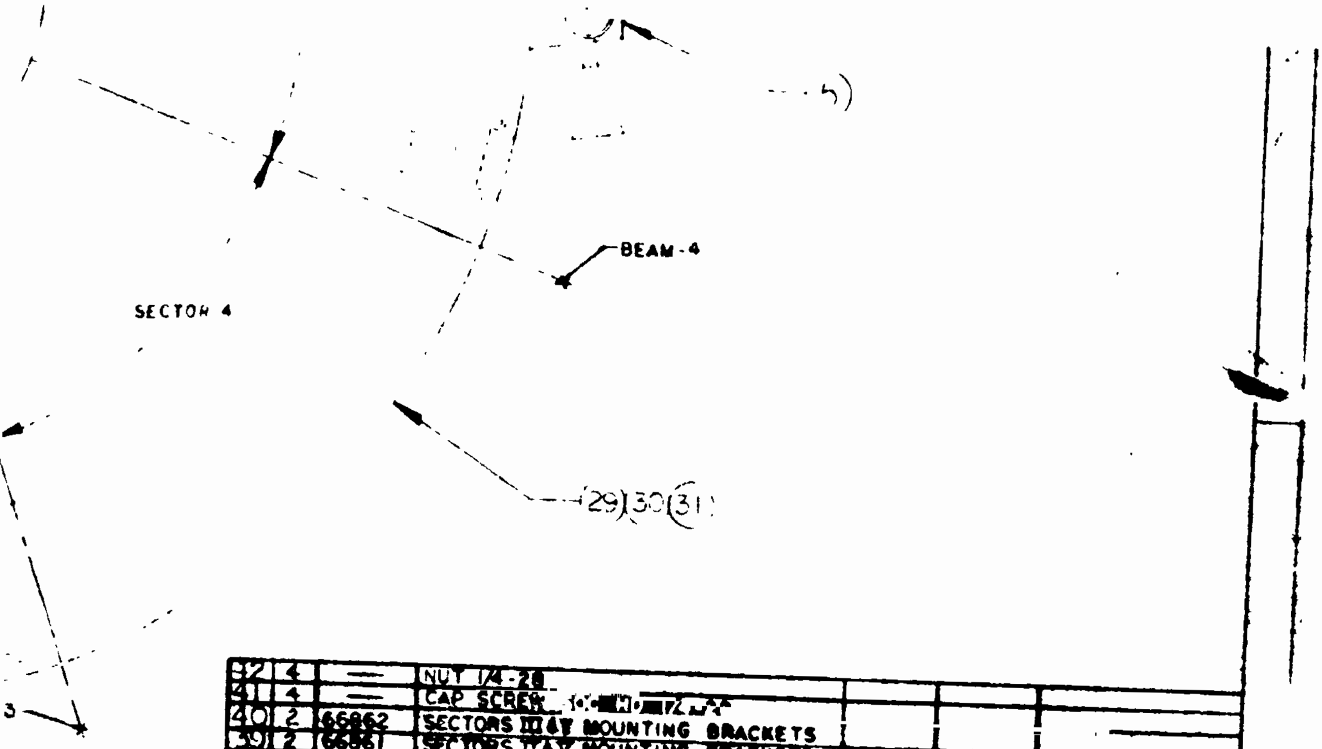
SIZE J

DWG NO 66855

REV B

SHEET 1 OF 1

FOLDOUT FRAME 10



ITEM	QTY	PART NO	DESCRIPTION	MAT'L	MAT'L SPEC	SOURCE
42	4	—	NUT 1/4-28			
41	4	—	CAP SCREW [illegible]			
40	2	66862	SECTORS III & V MOUNTING BRACKETS			
39	2	66861	SECTORS II & V MOUNTING BRACKETS			
38	8	—	#4 FLAT WASHER			
37	4	—	#4-40 HEX NUTS			
36	6	—	#4-40 X .50 LG SOC HD CAP SC			
35	1	66856-5	WEIGHT BLOCK SECT 5			
34	1	66856-6	WEIGHT BLOCK SECT 6			
33	1	[illegible]-2	WEIGHT BLOCK SECT 2			
32	1	66856-3	WEIGHT BLOCK SECT 3			
31	1	66542	OUTER SHELL SECT 4 DOOR			
30	1	66535	OUTER SHELL SECT 4 AFT.			
29	1	66528	OUTER SHELL SECT 4 FWD.			
28	1	66545	OUTER SHELL SECT 1 DOOR			
27	1	66554	OUTER SHELL SECT 1 AFT.			
26	1	66550	OUTER SHELL SECT 1 FWD			
25	2	66390	OUTER SHELL SECT 3 & 6			
24	2	66393	OUTER SHELL SECT 2 & 5			
23	6	—	#2-56 HEX NUTS			
22	3	—	SPHERICAL WASHER			
21	3	—	#2-56 X 1.50 LG TH'D ROD			
20	12	66860	STRAIN GAGE LEADS 126 STR SHLD 3 COND		12-B	W.T. BEAN INC.
19	[illegible]	[illegible]	STRAIN GAGE		C13 R345E STK	DENTRONICS INC.
18	1	[illegible]	LEM CONE SUPPORT			
17	1	66857	LEM CONE SUPPORT RING			
16	3	—	CLEVIS PIN - .062 DIA.			
15	2	[illegible]	0-80 X .19 LG SOC HD CAP SC.			
14	[illegible]	[illegible]	[illegible] CONE FAIRING			
13	8	—	ACCELEROMETER CABLE			
12	[illegible]	—	ACCELEROMETER		LN-3	NASA.
11	[illegible]	—	[illegible] .25 DIA. - .38 LG 10-24 THD		606-2	NASA.
10	6	—	ALIGNMENT SC #1-72 X .50 LG RD HD.			
9	3	66380	CLEVIS-MODULE ATTACHMENT			
8	1	66303	S/M FAIRING			
7	2	66399	PANEL-SHELL-TYP SECT 3 & 6			
6	10	—	#0-80 X .18 LG — OVAL FILL HD SC.			
5	2	66836-	E-2 R.C.S. PANEL ASS'Y			
4	2	66836-	E-1 R.C.S. PANEL ASS'Y			
3	1	66850	SERVICE MODULE-INTERNAL ASS'Y			
2	1	[illegible]	STING			
1	1		CAPSULE ASSEMBLY			NASA P/N 507654

LIST OF MATERIALS OR PARTS

TITLE	1/10 SCALE APOLLO DYNAMIC MODEL ASSEMBLY	
JOB NO 2411	SIZE J	DWG NO 66855
SCALE FULL	CUSTOMER NASA-MSC	REV B
		SHEET 1 OF 1

FOLDOUT FRAME 10